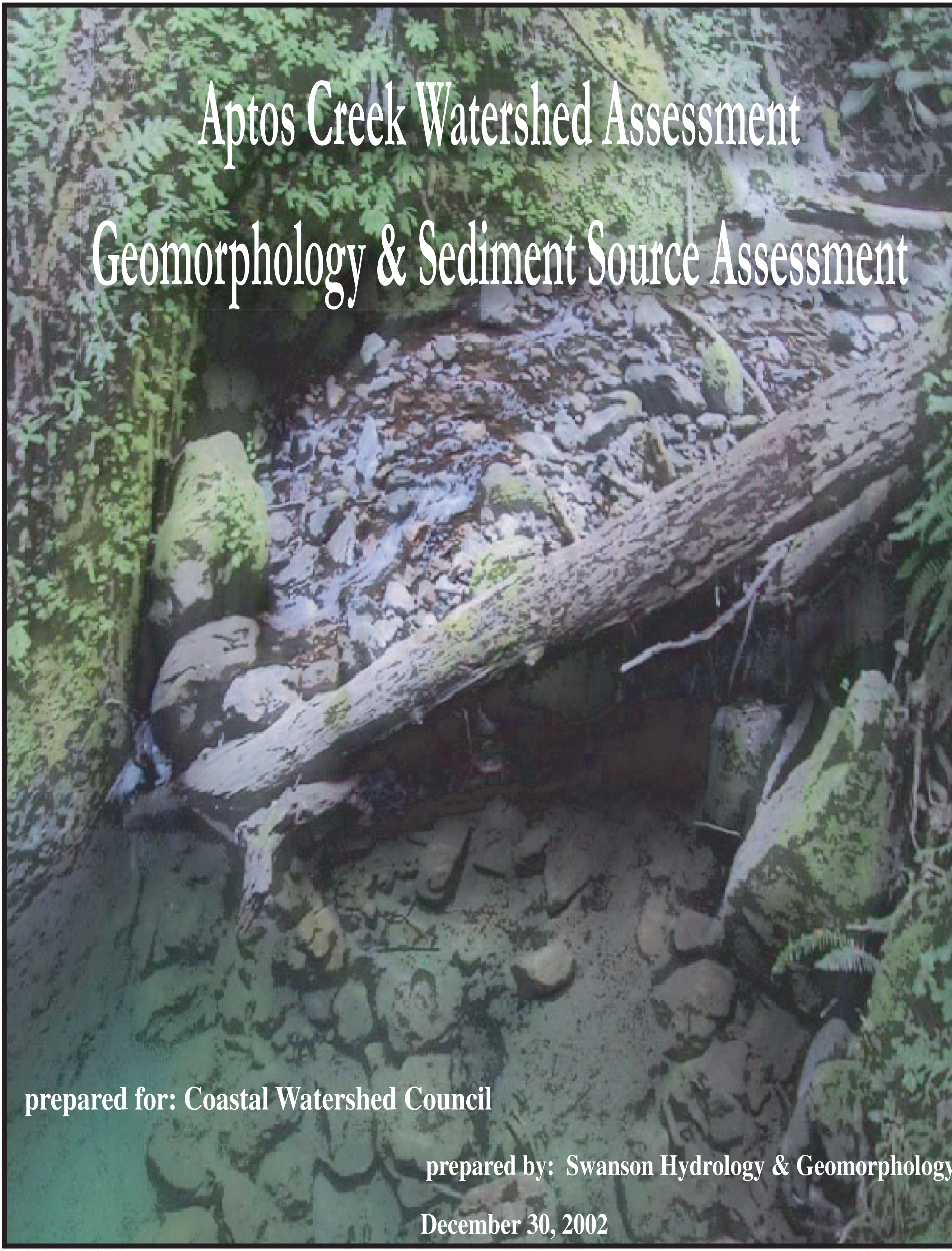

Aptos Creek Watershed Assessment

Geomorphology & Sediment Source Assessment

prepared for: Coastal Watershed Council

prepared by: Swanson Hydrology & Geomorphology

December 30, 2002

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1.0 – INTRODUCTION

1.1 – PROBLEM STATEMENT

The Aptos Creek Watershed historically supported healthy runs of both steelhead trout (Oncorhynchus mykiss) and coho salmon (Oncorhynchus kisutch). Due to impacts, such as loss of watershed continuity (i.e.-barriers), excessive fine sediment loads, reduction in streamflow, degradation of water quality, modification to the coastal lagoon, and loss of channel complexity (e.g. – loss of floodplains, removal of woody debris), the population of these species have declined, or in the case of coho salmon, been lost completely. Both species have been listed under the Federal Endangered Species Act and targeted for restoration in Aptos Creek.

Impairment of rearing habitat and loss of pool depth due to deposition of fine-grained sediment is seen as a major contributing factor to reductions in steelhead and coho salmon populations in the watersheds draining the northern portion of Monterey Bay (San Lorenzo River, Soquel Creek, Aptos Creek; Swanson and Dvorsky, 2001; Alley, 2002; Dvorsky, Alley, and Smith, 2002). There are a variety of erosional processes that contribute sediment to stream channels, including landsliding, slumping, rilling, debris flows, and bank failures. Each process differs by the quantity, timing and grain size of sediment delivered to stream channels that may act as impairing sediment to salmonid production and rearing. Each process can also be classified into sources that are natural and those that are a result of human land use impacts. Erosion sources can also be classified into those that are episodic and those that are chronic. Based on results of the Zayante Area Sediment Study (Swanson and Dvorsky, 2001), it was found that chronic, fine sediment source were the most impairing to aquatic systems and in most cases, the most cost-effective and feasible sources to treat.

Once sediment reaches the channel, hydraulic conditions and channel geometry dictates the way delivered sediment is routed and sorted through the system. Stream reaches are often classified by their width to depth ratio and slope characteristics (Rosgen, 1994), which are variables that can be used to determine their competence to move sediment of different sizes. Human-induced changes to stream valleys can have a significant impact on channel function, especially when those impacts occur within the inner gorge of the stream valley. Road development along a stream corridor can have a significant impact on channel function by straightening and narrowing of the channel and encouraging the removal of woody debris. Narrowing and straightening of channels causes a reduction in hydraulic complexity that can limit sorting of fine sediment from coarser sediment and can reduce creation of important spawning and rearing habitat. Additionally, narrowing of the active channel results in downcutting of the channel, accelerated stream bank erosion and subsequent removal of floodplain sediments that end up being deposited in the lower reaches of the watershed where the hydraulic forces are not enough to transport delivered sediment.

Many factors influence the eventual deposition of fine sediment in pools and spawning beds, including the quantity of material eroding from the hillslope, the adjacency of these sources to stream channels, the grain size of the sediment supplied, and the ability of the stream channels to transport, store, and sort the delivered sediment load. In this technical memorandum, we will discuss the methods and results used to assess and quantify erosion sources and channel conditions in the Aptos Creek Watershed, and the potential impacts these sources have on steelhead populations. Our research approach aimed to take a comprehensive look at sediment sources and the depositional environment in the stream channels that both cause the erosion and limit natural movement of sediment through the system through hydraulic variability and properly functioning geomorphic conditions.

1.2 - BACKGROUND

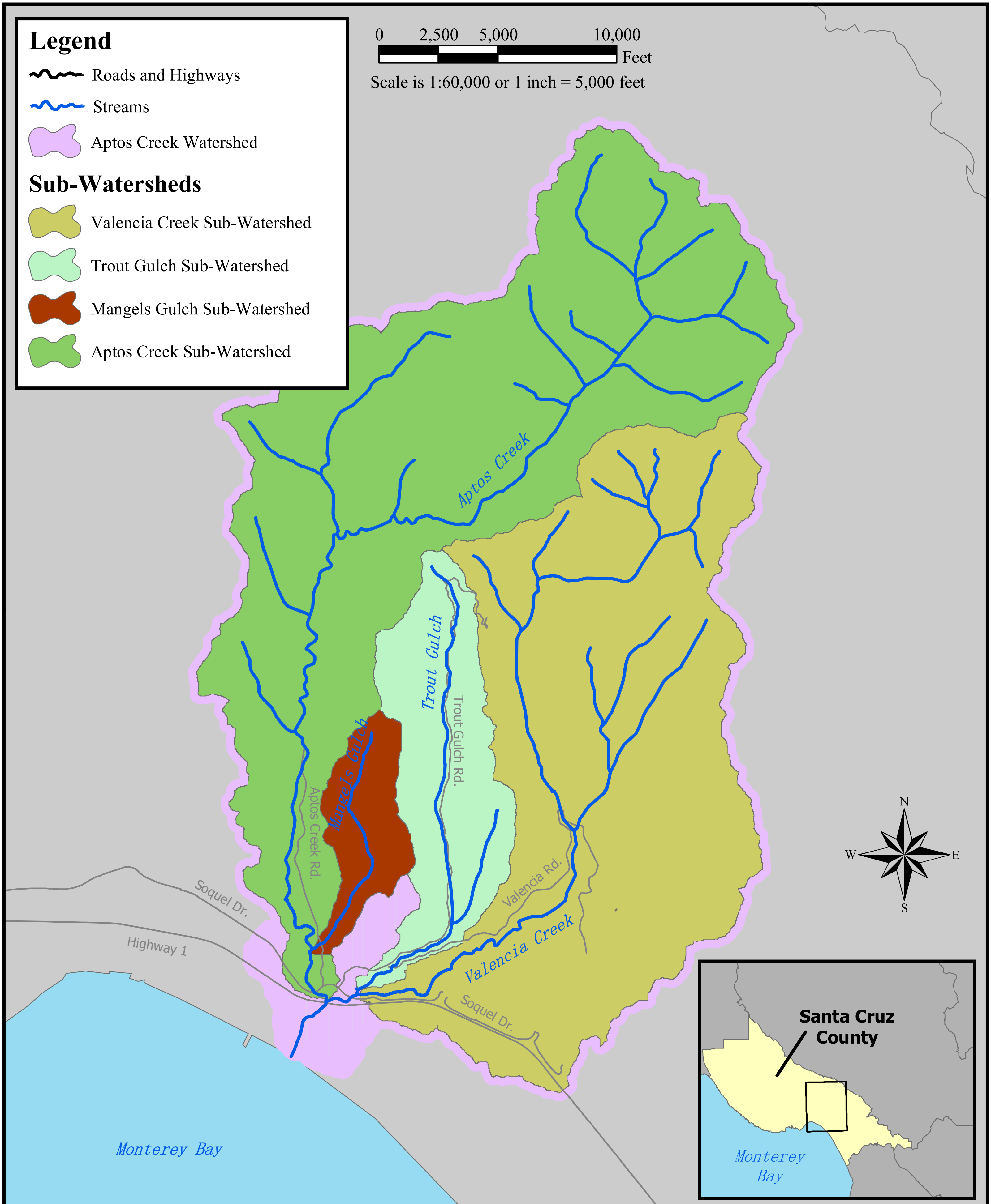
The Aptos Creek Watershed encompasses approximately 25 square miles of coastal land in southern Santa Cruz County, consisting of several major subwatersheds including Aptos Creek, Bridge Creek, Trout Gulch, Valencia Creek and Mangels Gulch (Figure 1). Approximately 60% of the watershed occurs within California State Parks property as the Forest of Nisene Marks, encompassing a large majority of Aptos and Bridge Creek subwatersheds. The remaining 40% of the watershed occurs on private land, consisting of a mix of forested, rural residential, suburban, and urban land in the Trout, Valencia, and Mangels subwatersheds.

1.2.1 – Geology

The geology of the Aptos Creek Watershed is dominated by the presence of the northwest-trending San Andreas Fault, a transverse fault that is characterized by lateral movement of the North American and Pacific Plates. The San Andreas Fault and associated Rosalia Ridge skirts the northeastern boundary of the watershed (Figure 2). The San Andreas Fault is considered to be very active in the study region, producing large magnitude seismic events, the most recent being the October 17, 1989 Loma Prieta earthquake. This 7.1 magnitude earthquake caused severe structural damage throughout the Bay Area and resulted in ground cracking and shallow landsliding throughout the Santa Cruz Mountains. The epicenter occurred within the Aptos Creek Watershed in the Forest of Nisene Marks State Park.

Other geologically important features include the Zayante Fault and the Glenwood Syncline. The Zayante Fault is thought to be an active fault system with seismic recurrence intervals on the order of 9,000 years (Petersen et. al., 1996). A recent magnitude 4.0 earthquake has been attributed to the Zayante Fault (Gallardo et. al., 1990). The Glenwood Syncline, which falls between the Zayante and San Andres fault system, is a dominant feature through Bridge Creek and upper Aptos Creek. The Glenwood Syncline appears to be consequent with a large portion of the landslides mapped in the Forest of Nisene Marks. Weber and Nolan (?), based on a preliminary analysis of mapped landslides in relation to geologic units, suggested that that correspondence of the two features may either be a function of focused energy within the syncline, or may represent a general weakness of the rocks near the fold axis due to brittle deformation within the fold. Therefore, hillslope instability in this region is likely related to regional geologic structure, as well as the morphology of the valley (i.e. – hillslope angle, inner gorge) and the underlying rock type.

In terms of surface exposure of lithologic units, the Purisima Formation is the dominant rock type, comprising 62% of the entire watershed. By subwatershed, the Purisima occurs in 69% of Aptos Creek, 92% in Mangels, 82% in Trout, and 51% in Valencia (Table 1). The Purisima Formation consists of a sequence of siltstones and sandstones that were formed in a marine environment during the Pliocene (2-11 million years B.P.). A significant proportion of the geologic units in the Aptos Creek Watershed consist of Quaternary deposits from the Pleistocene and Holocene (0-2 million years B.P.). Between 5 and 30 percent of the surficial geologic units are mapped as Quaternary deposits. In many cases, these relatively young deposits are unconsolidated and highly erodible when disturbed. They primarily occur within the Trout and Valencia Creek watersheds.



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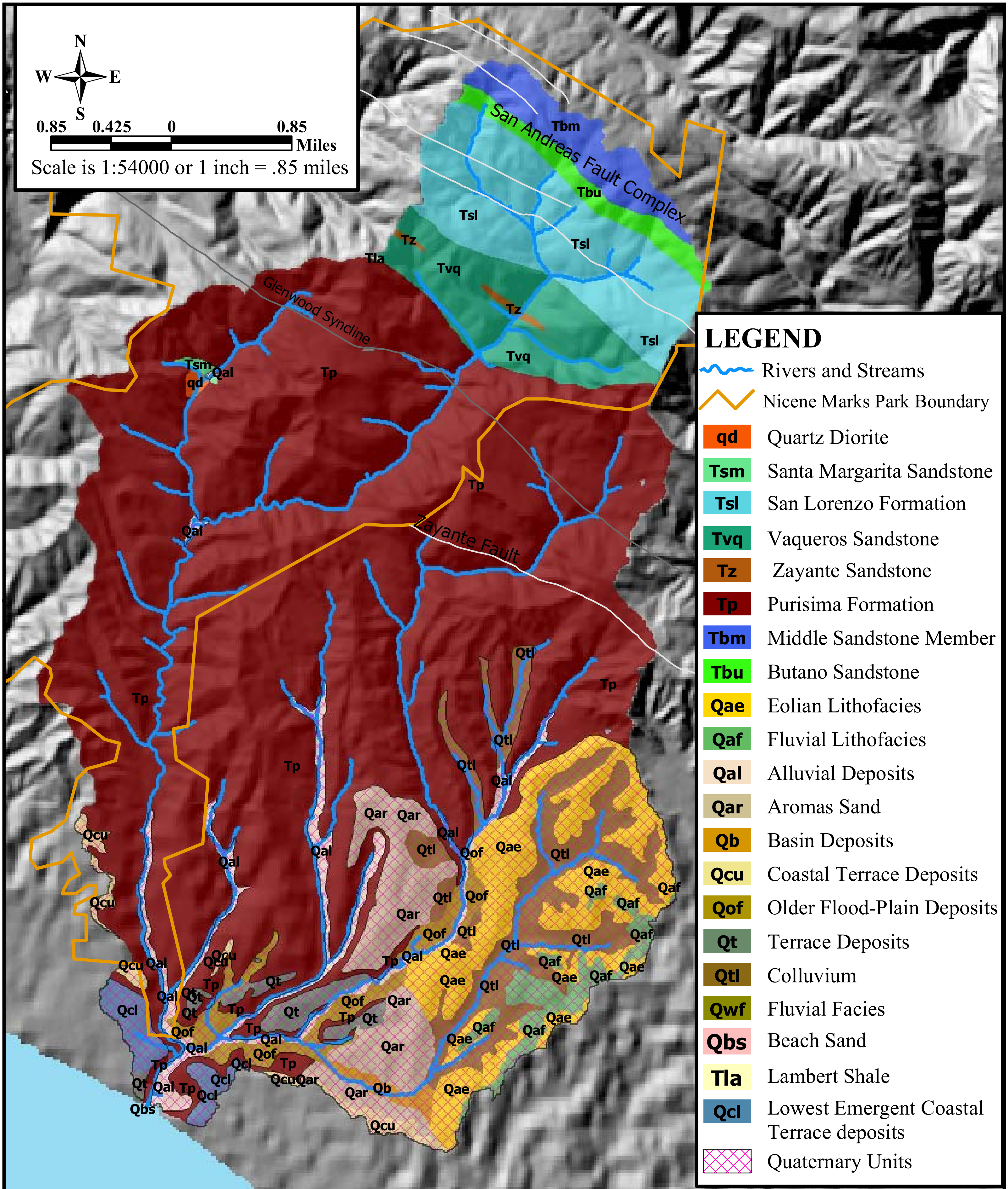
Aptos Creek Watershed
Sub-Watershed Delineation

Figure 1



Swanson Hydrology & Geomorphology 115 Limekiln Street Santa Cruz, CA 95060 tel: 831.427.0288 fax: 831.427.0472	Geologic Formations Aptos Creek Watershed Assessment and Enhancement Plan	Figure 2

Figure 2: Aptos Creek Watershed Assessment and Enhancement Plan

Geologic Unit Descriptions

Qae Eolian lithofacies- Moderately well sorted eolian sand. Highly variable degree of consolidation owing to differential weathering. May be as much as 200 ft thick without intervening fluvial deposits. Several sequences may be present, separated by paleosols. Upper 10 to 20 ft of each dune sequence is oxidized and relatively indurated, with all primary structures destroyed by weathering. Lower part of each dune sequence below weathering zone may be essentially unconsolidated

Qaf Fluvial lithofacies- Semiconsolidated, heterogeneous, moderately to poorly sorted silty clay silt, sand, and gravel. Deposited by meandering and braided streams. Includes beds of relatively well sorted gravel ranging from 10 to 20 ft thick. Clay and silty clay layers, locally as much as 2 ft thick, occur in unit. Locally includes buried soils, high in expansive clays, as much as 14 ft thick

Qal Alluvial deposits, undifferentiated (Holocene)- Unconsolidated, heterogeneous, moderately sorted silt and sand containing discontinuous lenses of clay and silty clay. Locally includes large amounts of gravel. May include deposits equivalent to both younger (Qyf) and older (Qof) flood-plain deposits in areas where these were not differentiated. Thickness highly variable; may be more than 100 ft thick near coast

Qar Aromas Sand, undivided (Pleistocene)- Heterogeneous sequence of mainly eolian and fluvial sand, silt, clay, and gravel. Several angular unconformities present in unit, with older deposits more complexly jointed, folded, and faulted than younger deposits. Total thickness may be more than 800 ft. Locally divided into:

Qb Basin deposits (Holocene)- Unconsolidated, plastic, silty clay and clay rich in organic material. Locally contain interbedded thin layers of silt and silty sand. Deposited in a variety of environments including estuaries, lagoons, marsh-filled sloughs, flood basins, and lakes. Thickness highly variable; may be as much as 90 ft thick underlying some sloughs

Qbs Beach sand (Holocene)- Unconsolidated well-sorted sand. Local layers of pebbles and cobblesThin discontinuous lenses of silt relatively common in back-beach areas. Thickness variable, in part due to seasonal changes in wave energy; commonly less than 20 ft thick. May interfinger with either well-sorted dune sand or, where adjacent to coastal cliff, poorly-sorted colluvial deposits. Iron-and magnesium-rich heavy minerals locally from placers as much as 2 ft thick

Qcl Lowest emergent coastal terrace deposits (Pleistocene)- Semiconsolidated, generally well-sorted sand with a few thin, relatively continuous layers of gravel. Deposited in nearshore high-energy marine environment. Grades upward into eolian deposits of Manresa Beach in southern part of county. Thickness variable; maximum approximately 40 ft. Unit thins to north where it ranges from 5 to 20 ft thick. Weathered zone ranges from 5 to 20 ft thick. As mapped, locally includes many small areas of fluvial and colluvial silt, sand, and gravel, especially at or near old wave-cut cliffs

Qcu Coastal terrace deposits, undifferentiated (Pleistocene) Semiconsolidated, moderately well sorted marine sand with thin, discontinuous gravel-rich layers. May be overlain by poorly sorted fluvial and colluvial silt, sand, and gravel. Thickness variable; generally less than 20 ft thick. May be relatively well indurated in upper part of weathered zone

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Figure 2 (continued): Aptos Creek Watershed Assessment and Enhancement Plan

Geologic Unit Descriptions

qd Quartz diorite (Cretaceous)- Grades to granodiorite south and east of Ben Lomond Mountain

Qof Older flood-plain deposits (Holocene)- Unconsolidated, fine-grained sand, silt, and clay. More than 200 ft thick beneath parts of the Pajaro and San Lorenzo River flood plain. Lower parts of these thick fluvial aggradational deposits include large amounts of gravel, and serve a major ground-water aquifer beneath Pajaro Valley

Qt Terrace deposits, undifferentiated (Pleistocene)- Weakly consolidated to semiconsolidated heterogeneous deposits of moderately to poorly sorted silt, silty clay, sand, and gravel. Mostly deposited in a fluvial environment. Thickness highly variable; locally as much as 60 ft thick. Some of the deposits are relatively well indurated in upper 10 ft of weathered zone

Qtl Colluvium (Holocene)- Unconsolidated, heterogeneous deposits of moderately to poorly sorted silt, sand, and gravel. Deposited by slope wash and mass movement. Minor fluvial reworking. Locally includes numerous landslide deposits and small alluvial fans. Contacts generally gradational. Locally grades into fluvial deposits. Generally more than 5 ft thick

Tbm Middle siltstone member- Thin- to medium-bedded, nodular , olive-gray pyritic siltstone.Thickness about 700 ft (Clark, 1981, p. 8)

Tbu Upper sandstone member- Thin-bedded to very thick-bedded medium-gray , fine-to medium-grained arkosic sandstone containing thin interbeds of medium-gray siltstone. Thickness about 3,200 ft (Clark, 1981, p. 8)

Tla Lambert Shale (lower Miocene) -Thin- to medium-bedded and faintly laminated olive-gray to dusky-yellowish-brown organic mudstone containing phosphatic laminae and lenses in lower part. Thickness about 1,500 ft along Mountain Charlie Gulch (Clark, 1981, p. 16)

Tp Purisima Formation (Pliocene and upper Miocene)- Very thick bedded yellowish-gray tuffaceous and diatomaceous siltstone containing thick interbeds of bluish-gray semifriable, fine-grained andesitic sandstone. As shown, includes Santa Cruz Mudstone east of Scotts Valley and north of Santa Cruz. Thickness approximately 3,000 ft in the Corralitos Canyon area

Tsl San Lorenzo Formation, undivided (Oligocene and Eocene)

Tsm Santa Margarita Sandstone (upper Miocene)- Very thick bedded to massive thickly crossbedded yellowish-gray to white friable granular medium-to fine-grained arkosic sandstone; locally calcareous and locally bituminous. Thickness 430 ft along Scotts Valley syncline (Clark, 1981, p. 25)

Tvq Vaqueros Sandstone (lower Miocene and Oligocene)- Thick-bedded to massive yellowish-gray arkosic sandstone containing interbeds of olive-gray shale and mudstone. Thickness 4,500 ft along Bear Creek (Burchfiel, 1958)

Tz Zayante Sandstone (Oligocene)- Thick- to very thick-bedded, yellowish-orange arkosic sandstone containing thin interbeds of greenish and reddish siltstone and lenses and thick interbeds of pebble and cobble conglomerate. Thickness 1,800 ft along Lompico Creek (Clark, 1981, p. 14)

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Geologic Unit	Abreviation	Entire Watershed		Aptos Creek Sub-Watershed		Mangels Gulch Sub-Watershed		Trout Gulch Sub Watershed		Valencia Creek Sub Watershed	
		Area (acres)	Percent	Area (acres)	Percent	Area (acres)	Percent	Area (acres)	Percent	Area (acres)	Percent
Eolian Lithofacies	Qae	891	5.7	0	0.0	0	0.0	0	0.0	891	14.8
Fluvial Lithofacies	Qaf	219	1.4	0	0.0	0	0.0	0	0.0	219	3.6
Alluvial Deposits	Qal	387	2.5	103	1.3	46	8.4	127	8.5	109	1.8
Aromas Sand	Qar	580	3.7	0	0.0	0	0.0	106	7.1	474	7.9
Basin Deposits	Qb	58	0.4	0	0.0	0	0.0	0	0.0	58	1.0
Beach Sand	Qbs	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Lowest Emergent Coastal Terrace Deposit	Qcl	152	1.0	17	0.2	0	0.0	0	0.0	2	0.0
Coastal Terrace Deposits	Qcu	117	0.7	42	0.5	0	0.0	0	0.0	56	0.9
Quartz Diorite	qd	14	0.1	14	0.2	0	0.0	0	0.0	0	0.0
Older Flood Plain Deposits	Qof	282	1.8	13	0.2	0	0.0	9	0.6	190	3.2
Terrace Deposits	Qt	151	1.0	4	0.1	0	0.1	24	1.6	91	1.5
Colluvium	Qtl	858	5.5	0	0.0	0	0.0	0	0.0	858	14.3
Middle Sandstone Member	Tbm	315	2.0	315	4.1	0	0.0	0	0.0	0	0.0
Butano Sandstone	Tbu	179	1.1	179	2.3	0	0.0	0	0.0	0	0.0
Lambert Shale	Tla	2	0.0	2	0.0	0	0.0	0	0.0	0	0.0
Purisima Formation	Tp	9,816	62.5	5,344	69.2	499	91.6	1,224	82.2	3,071	51.0
San Lorenzo Formation	Tsl	997	6.3	997	12.9	0	0.0	0	0.0	0	0.0
Santa Margarita Sandstone	Tsm	13	0.1	13	0.2	0	0.0	0	0.0	0	0.0
Vaqueros Sandstone	Tvq	662	4.2	662	8.6	0	0.0	0	0.0	0	0.0
Zayante Sandstone	Tz	21	0.1	21	0.3	0	0.0	0	0.0	0	0.0

Table 1: Land surface area within each geologic unit by subwatershed. The geologic units with the highest percentage of land surface within each subwatershed are highlighted in gray. The Purisima Formation covers approximately 2/3rds of the entire Aptos Watershed.

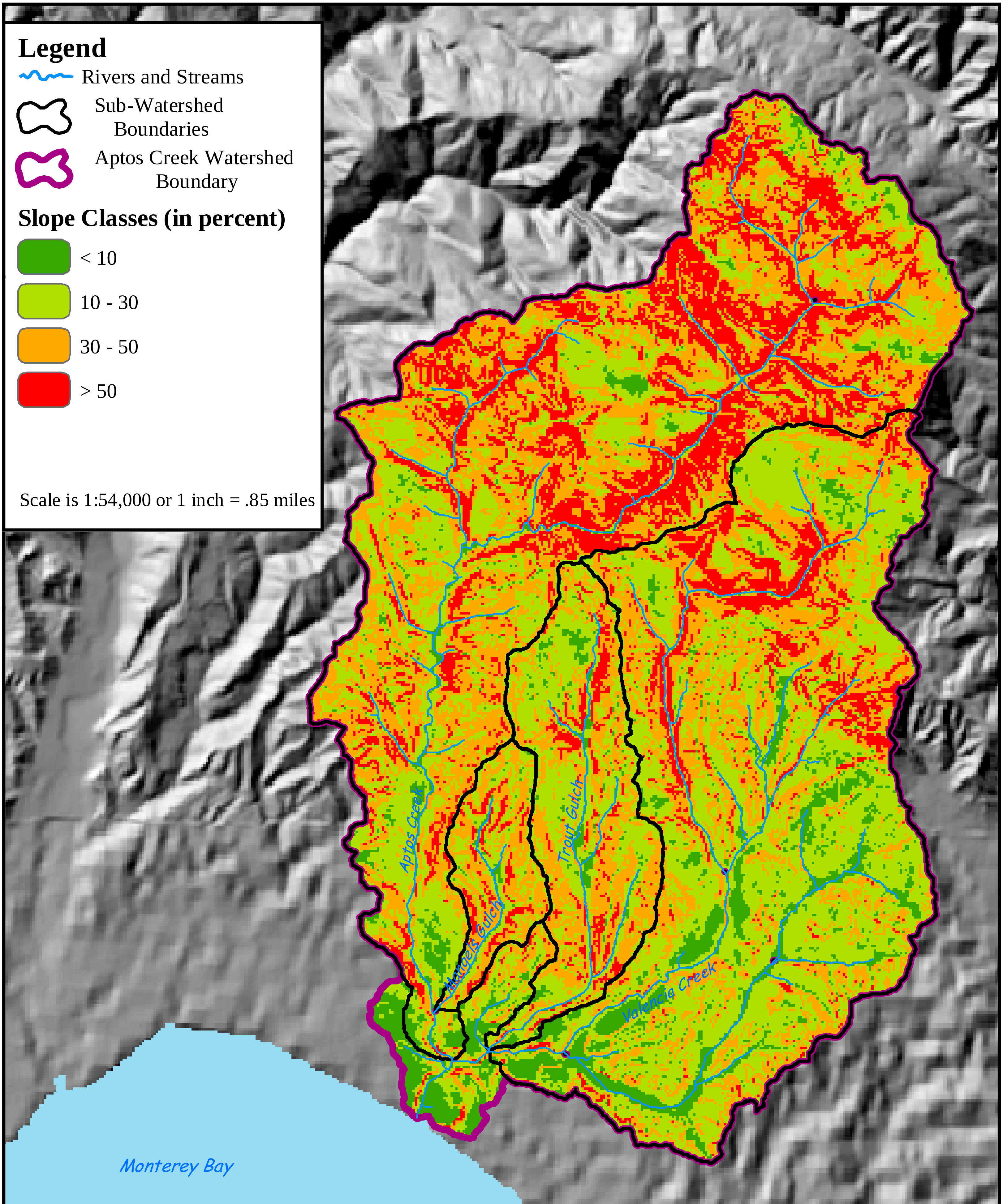
1.2.2 – Erosion Sources

A variety of landslides ranging from shallow debris flows to rotational slumps over a hundred feet deep are found in the Santa Cruz Mountains and the Aptos Creek Watershed. Landsliding (or mass wasting) is the dominant geomorphic process in the Santa Cruz Mountain landscape. Landsliding results from weak geologic formations, steep topography caused by tectonic uplift, and occurrence of intense periods of rainfall and seismic forces. Landslides often terminate at and impinge upon stream channels, sometimes feeding a seemingly endless supply of sandy material directly into the channels. In the worst cases, chronic sediment loading from landslides can eliminate pools, riffles and coarse substrate for hundreds of feet below the point of delivery. An important mechanism to store delivered sediment and attenuate sediment delivery downstream relates to the presence of large woody material and debris jams (Keller and Talley, 1979; Keller et al., 1981).

This is an example of woody material resulting in storage of coarse and fine material within the channel. Storage is likely to occur for approximately 100-200 feet upstream of the log.

Steep slopes are an important factor in erosion in general and for landslides in particular. Figure 3 show slope class gradients for the Aptos Creek Watershed. The steepest slopes in the Aptos Creek Watershed are located in the Forest of Nisene Marks, along the headwaters near the summit and along the inner gorge slopes. The lowest gradients are found in the alluvial valleys along streams in the lower watershed areas.

Mapped landslides make up a substantial proportion of the overall sediment budget. The large slides are deep failures that often extend from ridge top to the canyon floor and stream. The speed of the active mass can range from inches per year to tens of feet per day. As a large slide moves along a distinct failure plane, the landmass on the upper part of the slide is lowered and depleted, while the lower toe area expands and bulges into the stream canyon or valley. The bulging of the toe has several significant effects on sediment delivery and



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sensitivity to land disturbance. First, the rock is fractured, weakened and subject to saturation and greater weathering while it is being transported closer to the stream; this makes the mass simultaneously steeper and weaker, enhancing gully erosion and shallow mass failures on the toe face. As the stream incises or if a road is cut along the canyon wall, the landslide toe is eroded and the mass buttressing the slide above is removed, causing the slide to move further down slope. This lower zone of canyon slopes where incision dominates is called the "inner gorge". The inner gorge is generally steeper than the hillslope above and in addition to landslide toes; it often contains deeply weathered bedrock and colluvium.

Weathered bedrock, soils and colluvium are subject to saturation by rainfall. Saturated conditions can produce a nearly instantaneous and deadly failure of a rapidly moving landslide called *debris flows*. Debris flow failures are common along the inner gorge slopes of the Santa Cruz Mountains. Debris flows occur during intense periods of rainfall after hundreds of years of persistent slope wash and colluvium accumulation in swales. The swales are often bedrock, which has a lower permeability than the overlying colluvium. When the rate of rainfall exceeds the rate that the colluvium and soil can drain water off, the saturated zone or water table above the less permeable bedrock deepens. When the saturated mass overcomes the resistance holding it on the hillslope, the mass liquefies instantly and moves down the hillslope carrying trees, soil, propane tanks and sometimes entire houses. In some cases, water separates from the debris flow mass as it reaches lower gradients and a debris torrent is unleashed - a wall of mud and debris that moves very fast and is extremely destructive. Debris flows and torrents commonly form the small alluvial fans distributed along the edges of higher order stream valleys at the end of ephemeral tributary basins. In the January 2-4, 1982 storms, debris flows and nearly continuous shallow failures in the inner gorge slopes occurred throughout the Santa Cruz Mountains.

Road building is a common and often dominant theme in land use disturbance. From timber harvests to driveways and public thoroughfares, roads are required for access to nearly every land use. Roads are also by far the most destructive element in the landscape as far as excessive fine sediment generation per unit area. Roads constructed along canyon floors and steep inner gorge slopes cause channel realignment resulting in direct delivery of sediment to streams.

Erosion from road surfaces, ditches, shoulders and other human-induced land clearing contribute mostly fine-grained sediment. Paved and unpaved roads modify local hillslope drainage patterns, concentrate flow and increase runoff rates. Runoff on roads concentrates over soils exposed on the roadbed and shoulder, drainage ditches, road cuts, sidecasts and fills. In terms of managing sediment loads to reduce aquatic habitat impairment, fine sediment source reduction from roads will be the most effective treatment. Roads are the primary cause of human-induced or "accelerated" erosion throughout the Santa Cruz Mountains from both timber harvest activities and rural residential roads.

Bank erosion and reworking of old floodplain deposits also contributes significantly to the amount of fine sediment in the channel. These sources contribute fine sediment directly to the channel and have a significant impact on aquatic habitat conditions. Reworking of old floodplain deposits that might have been delivered to the stream channel due to historic and intensive logging operations may be especially important in the Valencia and Trout Creek watersheds due to urbanization impacts that have affect the hydrologic condition. To what extent reworked floodplain deposits has an impact on aquatic habitat conditions is largely unknown.

2.0 – METHODS

2.1 – SEDIMENT BUDGET

Development of a sediment budget is an approach that considers the erosional processes occurring in a particular study area and attempts to quantify the amount of material being delivered and transported past a specific point. If the amount of sediment being delivered exceeds the amount of sediment being transported, aggradation is the dominant process. If the amount of sediment being delivered exceeds the amount being transported, the stream channel is likely to be incising. If both delivery and transport of sediment are equal, the stream channel is said to be in equilibrium.

This simplified notion of a sediment budget is complicated by the fact that both sediment delivery and transport within a stream channel is a stochastic process (Benda and Dunne, 1997a; Benda and Dunne, 1997b). This means that sediment delivery to the channel occurs episodically through mast wasting events such as landslides or debris flows. Sediment transport is also a function of the magnitude, duration, and energy associated with streamflow, which has a significant range over time periods as short as a few hours. Sediment transport volumes during wet years can be orders of magnitude greater than those recorded in drought years. The same is true for sediment delivery. During wet years, a saturated hillslope in the steep inner gorge is much more likely to fail and deliver sediment to a stream channel than the same hillslope during a dry year. Over time, it is likely that episodic delivery and transport events even out, producing what is known as a system in dynamic equilibrium. The question often remains, over what time scale is the concept of dynamic equilibrium occurring within any given reach of stream.

The stochastic nature of sediment delivery and transport makes it very difficult to accurately estimate a sediment budget given limited data. Monitoring movement of suspended and bed load material passing a set location, such as a bridge, would require one to two decades of data to capture the range of flow and sediment events that characterize the stochastic nature of the process. It would not be uncommon for a single year, within a 20-year dataset, to represent over 50% of the total sediment load measured during that period. If that single year were removed, the average flux of sediment, per year, would be greatly underestimated.

There are also difficulties in estimating the supply side of the sediment budget equation that go beyond the stochastic nature of the process. In many cases it is very difficult to apply a rate to any particular erosion source. Sources of erosion can easily be identified in the field, and the volume of sediment being eroded and delivered to an adjacent stream channel can be estimated. The difficulty lies in estimating the rate at which the sediment is being delivered. Without information about how long ago a particular source began to erode, volume information becomes meaningless.

In some cases this problem has been overcome through the use of aerial photo series. Several photo dates can be examined to constrain the date at which a particular erosion feature, such as a landslide, began delivering sediment. By estimating sediment volumes from many landslides throughout a particular watershed from a series of aerial photos, a landslide rate for the landscape of interest can be estimated (Reid and Dunne, 1994). Unfortunately, aerial photo interpretation of erosion features becomes problematic in a landscape with dense tree cover. Features such as landslides, debris flows, or gullies are in most cases impossible to see, unless they are recent or very large. Mapping these features in a densely forested area with the intent of estimating a sediment budget can be very misleading.

The quality of the results generated from a sediment budget will ultimately be related to the quality of the input data and the amount of time and information that is available to accurately construct one. To accurately quantify the rate at which sediment in being supplied to the channel would require years of intensive data collection and monitoring equipment, as well as access to all potential sources. Since an intensive approach is not realistically feasible, the best approach lies in identifying the most significant sources of sediment, obtaining as much information as possible about the physical setting of the landscape that might infer a certain rate of erosion, and applying published erosion rates from other watersheds that exhibit similar patterns of erosion.

Regardless of the difficulties in estimating sediment budgets, particularly in forested areas, the results can be a valuable dataset when attempting to understand the dominant erosional processes and the sources of sediment that may be impairing valuable aquatic habitat. The exercise of estimating a sediment budget requires careful consideration of each potential source, the magnitude of delivery by that source, a description of the grain-sizes being delivered, and a comprehensive understanding of the transport hydraulics within a stream channel. Even though the final sediment budget numbers may contain a significant amount of error, there is much to be understood from them. The magnitude to which each source contributes to the overall sediment budget and the location of those sources within the watershed, as a whole, are valuable pieces of information that can guide current and future management.

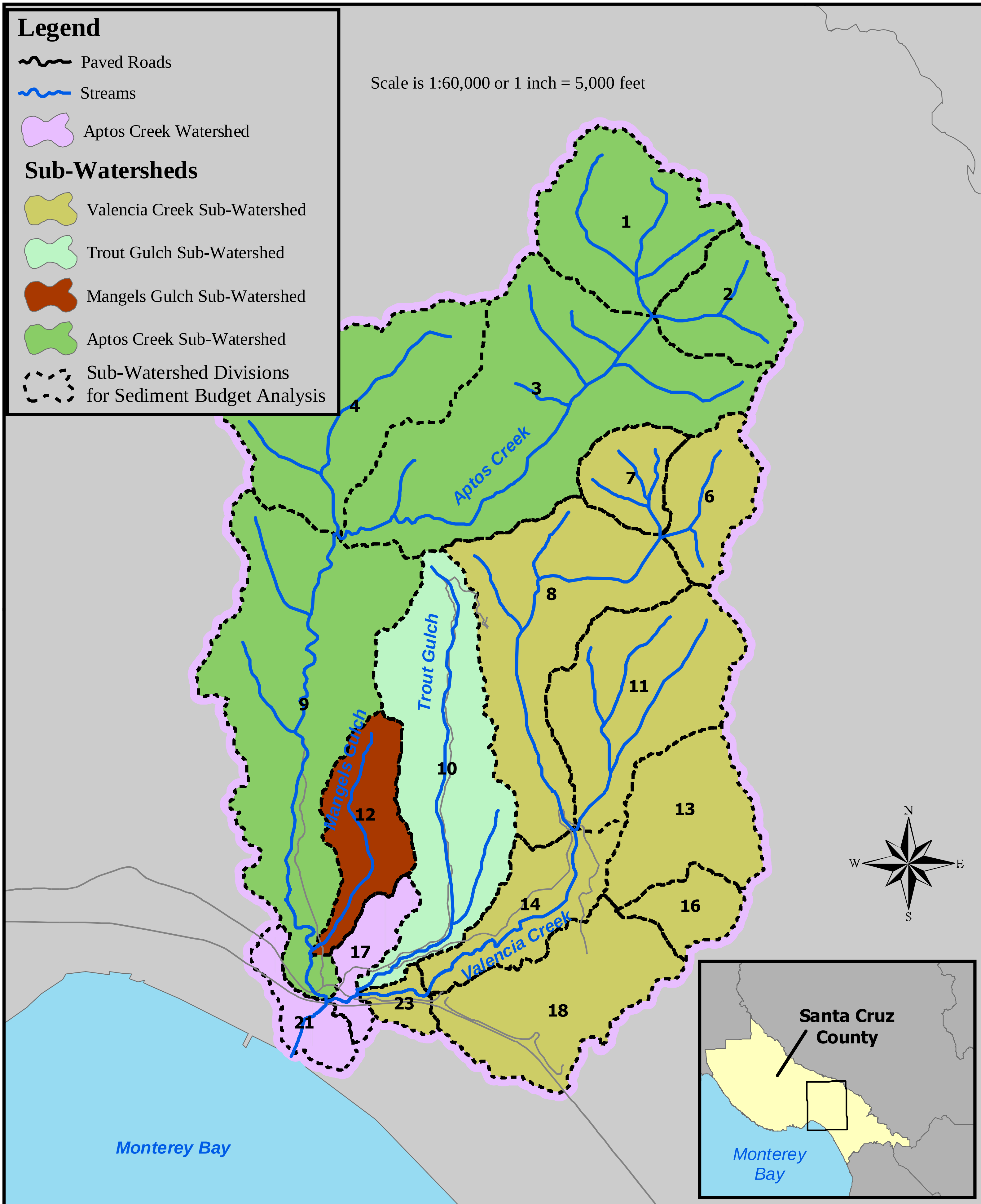
The remainder of this section will describe the approach used to estimate a sediment budget for the Aptos Creek Watershed. Much of the approach is based on erosion estimates developed by the California Department of Forestry (CDF) for the Soquel Demonstration Forest (Cafferata and Poole, 1993) and utilized effectively in the Zayante Area Sediment Source Study (Swanson and Dvorsky, 2001).

2.1.1 – Subwatershed Delineation

The first step in developing a sediment budget is to determine the location at which we are interested in quantifying the amount of sediment being transported through the system. Since we are concerned about the conditions of the entire watershed, the most logical location would be at the mouth of Aptos Creek as it enters the Pacific Ocean. Upstream of this location lies a variety of subwatersheds that exhibit different morphologic, geologic, and land use conditions that must be considered to accurately estimate rates of erosion and sediment input to the stream channel.

To capture the variability in landscape and land use conditions in the watershed, while at the same time taking advantage of the dendritic nature of stream channels, we divided the watershed into subwatershed areas, as defined by the confluence of tributary inputs and/or significant changes in the dominant rock type (Figure 4). Subwatersheds were delineated automatically using a USGS 30-meter digital elevation model of the landscape based on points manually selected that represented the lowest "pour point" within each subwatershed. Standard GIS algorithms were used to derive the subwatershed boundaries from the input digital data source.

The derived watersheds were the primary analysis units used to calculate erosion from the landscape and estimate sediment delivery to the channel, except for the bank erosion



Swanson Hydrology and Geomorphology 115 Limekiln St. Santa Cruz, CA 95060 tel. 831-427-0288 fax. 427-0472	Aptos Creek Watershed Sub-Watershed Delineation	Figure 4

components of the sediment budget, which used stream reach delineations (discussed later). A total of 18 subwatersheds were delineated for the Aptos Creek Watershed. The subwatersheds range in size from 100 acres (the area below the confluence of Aptos and Valencia) to 2,300 acres (Upper Aptos Creek) with an average size of approximately 870 acres (1.35 mi^2).

To simplify reporting of the final sediment budget, the subwatersheds were combined into four subwatershed areas representing Aptos, Mangels, Trout, and Valencia Creeks. Information generated for each analysis-level subwatershed was combined using a drainage area weighted average of the per unit sediment yield.

2.1.2 – Sediment Budget Calculations

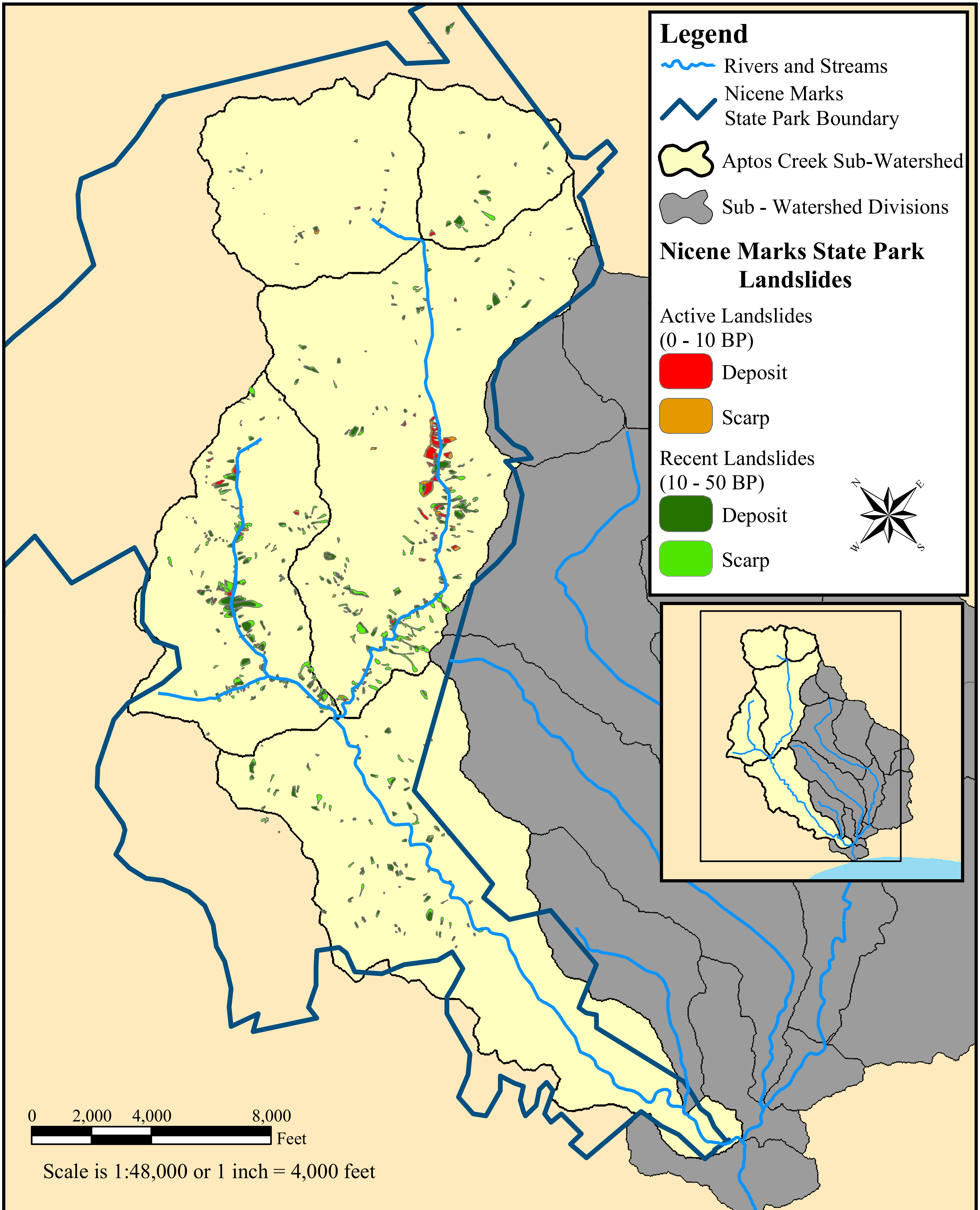
Mass Wasting

In the Zayante Area Sediment Source Assessment (Swanson and Dvorsky, 2001), the best data available to estimate erosion and delivery rates from mass wasting was a USGS GIS product depicting landslides for Santa Cruz County (Cooper-Clark and Associates, 1974). This product, though useful for identifying the density of landslides on the landscape, provides no information regarding the age of the landslide. Without age information, an erosion rate cannot be calculated and must be grossly estimated.

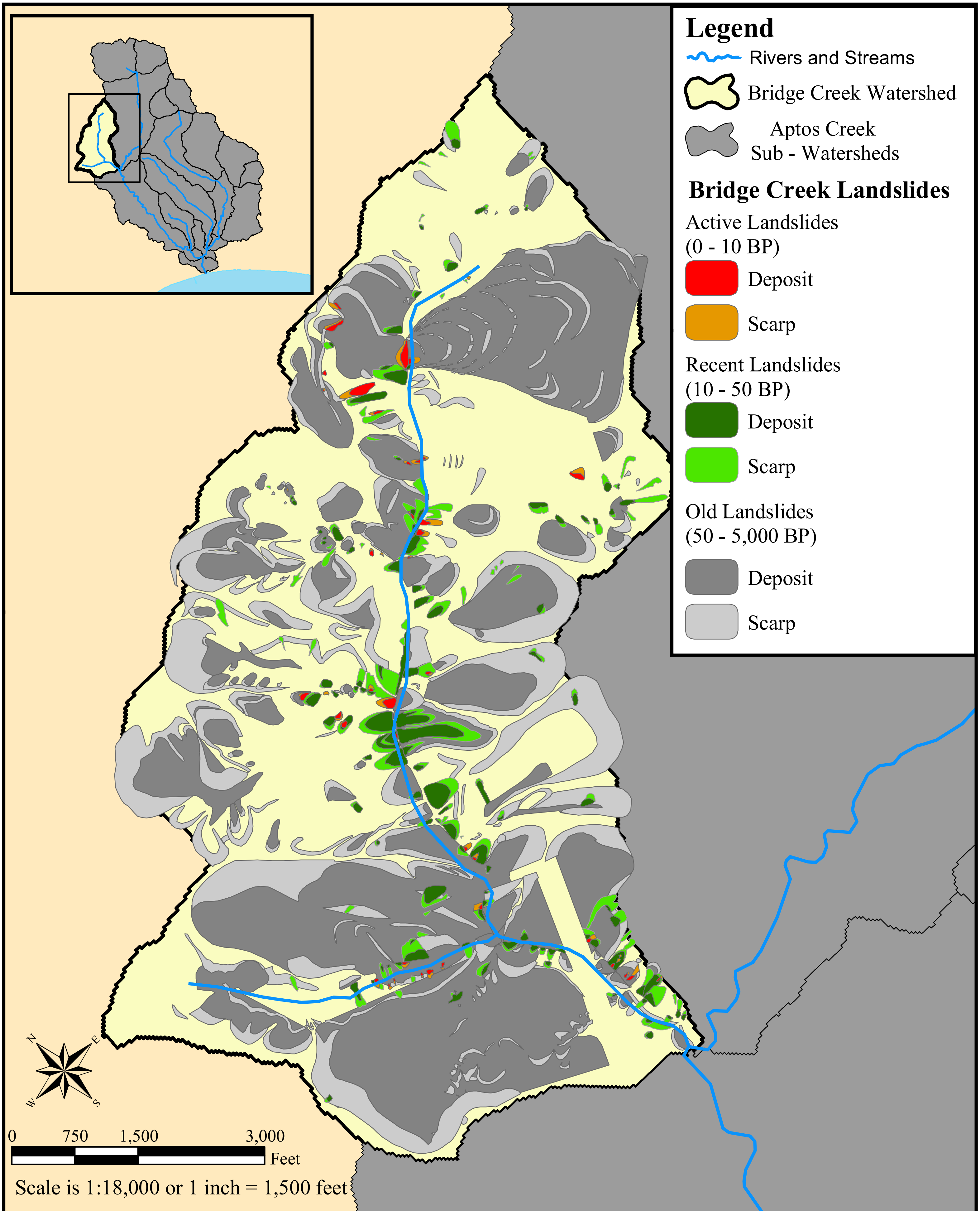
Fortunately, for the Aptos Creek Watershed, a wealth of information is available for the Forest of Nisene Marks State Park portion of the watershed. Following the Loma Prieta earthquake that occurred in October of 1989, Weber and Nolan (?) were funded to map landslides, using field identifications in Nisene Marks, with special attention paid to recent landsliding associated with the Loma Prieta earthquake. In addition to the location and extent of each landslide, general information was collected regarding the type of landslide (e.g. – rotational, translational, debris flow) and an estimate of the age within an age category consisting of those occurring within the last 10 years, the last 50 years, and older. Each landslide was mapped on a 1:24,000 USGS quadrangle.

SH&G acquired the original maps and produced a digital version by digitizing each feature (Figure 5). Each feature was assigned attributes defining the estimated age of the slide and whether the feature was a slide mass or a scarp. Information regarding the mechanism was excluded from the GIS database. Since the volume of data was immense, only slides estimated to have occurred within the last 50 years were digitized for the entire study area within the Aptos Creek Watershed. In the Bridge Creek subwatershed, all features depicted on the maps were digitized so as to provide a complete dataset for one subwatershed (Figure 6). Only mass wasting features determined to be recent were included in the sediment budget calculations.

The final piece of information required to estimate the volume of sediment that was available from each mass wasting feature is an average depth for each slide mass. Unfortunately, the landslide map does not provide the necessary information to determine this. The volume of sediment from each feature was estimated by assuming an average depth of ten feet. A depth of ten feet was assumed since a large proportion of the recent slides was determined to be of the shallow, translation type, rather than deep rotational slides (Weber and Nolan, ?). The surface area of the slide mass was used with this average depth to calculate a volume for each slide. The volumes were then used to estimate sediment yield rates according to the age of each mass wasting feature. An assumed age of 50 years was used for the recent slides while



Swanson Hydrology and Geomorphology 115 Limekiln Street Santa Cruz, CA 95060 tel: 831.427.0288 fax: 831.427.0472	Nisene Marks State Park Landslides Aptos Creek Watershed Assessment and Enhancement Plan	Figure 5



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Bridge Creek Landslides
Aptos Creek Watershed
Assessment and Enhancement Plan

Figure 6

the active slides were assumed to be 10 years old. They represent the estimated maximum age of the slide according to the mapping data and are therefore considered to be a conservative estimate of the erosion rate.

In order to convert a sediment volume to a mass, we assumed a soil density of 123.5 lbs/ft^3 (Holtz and Kovacs, 1981). This is based on the predominance of fine-grained sand in the geologic and soil material within the watershed and that soils associated with mass wasting events would likely be moderately consolidated, as opposed to reworked material that might be found on the banks of the channel.

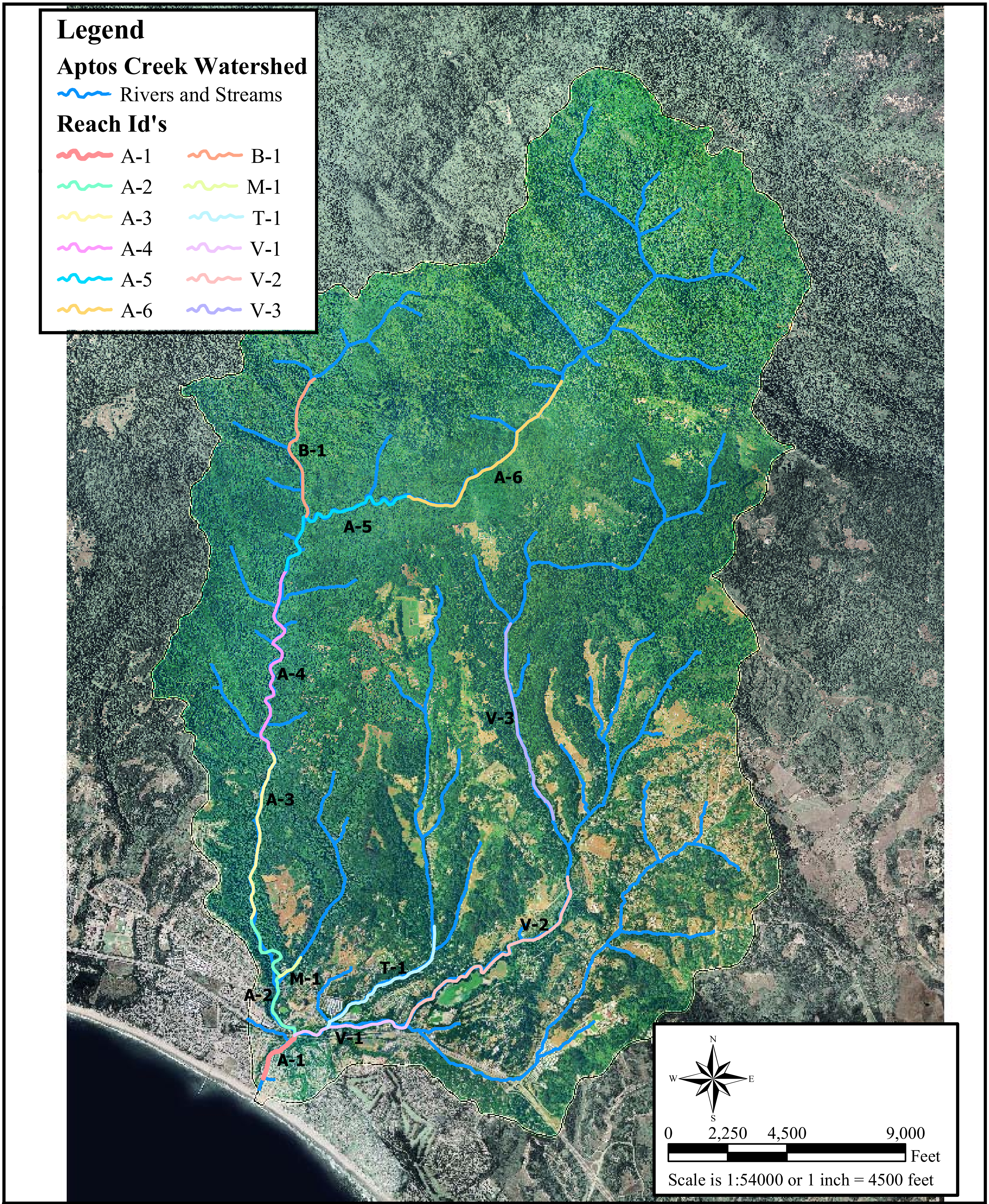
Since the landslide data was only available for the portion of the Aptos Creek Watershed found within the Forest of Nisene Marks, it was necessary to approximate the sediment volumes due to mass wasting for areas outside of the Park boundaries. The total mass wasting sediment volume for each subwatershed that occurred within the Park boundary was normalized by the corresponding sub-watershed's area and a weighted average for the mapped area was calculated. This average was then used to approximate sediment volumes for the subwatersheds outside of the park boundaries. The developed/urban areas in the lower Valencia and Aptos Creek subwatersheds were assumed to not experience significant mass wasting.

Bank Erosion

Bank erosion was estimated along a good portion of all the primary channels within the Aptos Creek Watershed, including Aptos, Bridge, Mangels, Trout, and Valencia. Field measurements were completed alongside the fisheries and large woody debris surveys and were compiled by stream reach (Figure 7). Reaches were delineated based on Rosgen's (1994) stream channel classification, which divides and classifies a stream based on local stream and valley morphology, gradient, and sediment characteristics. Each stream reach was walked and all significant bank erosion sites were either measured or the length of each erosion site was estimated using a hip chain measuring device to determine distance along surveyed stream reaches. The height of the bank erosion site was either measured directly using a stadia rod or was visually estimated. Information regarding the dominant grain size, the severity, and the level of stability were noted for each site.

This information was then used to estimate the total area (in ft^2) of bank erosion along each surveyed reach. The total length of each reach was then used to calculate an erosion area per mile of stream (ft^2/mi). This rate was then applied to all unsurveyed streams occurring within the same analysis subwatershed, with the assumption that the unsurveyed segments exhibit the same bank characteristics as the surveyed segment. We realize this assumption may not accurately depict the true erosion rate from streambanks due to differences between primary trunk streams and smaller tributaries, but we feel it is the best estimate available. It is unclear whether this assumption results in an over or under estimate of the eroding bank area.

The method described above only provides a two-dimensional picture of bank erosion in the Aptos Creek Watershed and does not allow for a direct calculation of the erosion rate. To make the jump from an erosion area to an erosion rate, we made several assumptions about the average depth and age of the observed bank erosion sites. Many of the erosion sites observed consisted of shallow composite failures due to undercutting. Based on this observation, we assumed the average depth was 2 feet. We also assumed an average age of 10 years. Bank erosion sites older than that would probably not be evident due to regrowth of



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vegetation, except in the case of chronic sites associated with landsliding. Those assumptions produce a retreat rate of 0.2 feet per year.

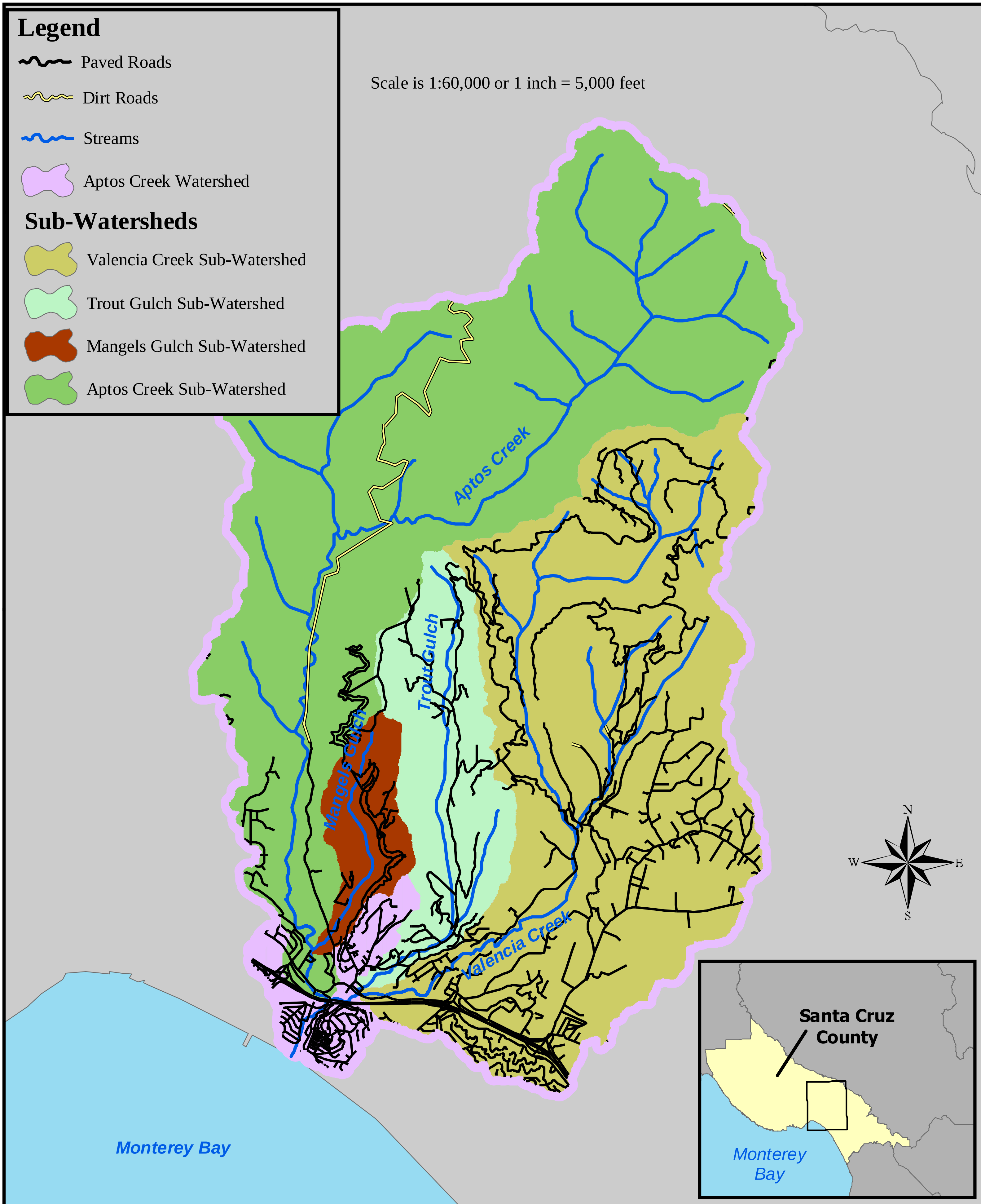
The estimated retreat rate was then used in conjunction with the area of erosion per mile of stream to produce a bank erosion sediment yield per mile of stream within each subwatershed (ft^3/mi/yr). To convert a volume to a mass, a value of 87.9 lbs/ft3 was used (Holtz and Kovacs, 1981). Bank deposits were assumed to be less dense than virgin landslide material and therefore a published rate associated with loosely consolidated silty sand was used.

Roads

The extensive efforts involved in a field survey of the road networks with in the Aptos Creek Watershed made it necessary to utilize sediment yield values determined in a CDF study of the East Branch of Soquel Creek (Cafferata and Poole, 1993). (Site-specific information related to erosion from roads may be available in the near future following survey work planned by CWC staff utilizing methods developed by Pacific Watershed Associates.) The Cafferata and Poole study occurred in an adjacent watershed and is likely to be the best locally available information on sediment yield off of both paved, dirt, and forest roads. This information was utilized successfully in the Zayante Area Sediment Study (Swanson and Dvorsky, 2001) and the San Lorenzo River TMDL (Angelo, 2002). The Aptos Creek Watershed is likely to be more suited for using this data due to the similarities in geology, topography, and vegetation, compared to the Zayante Area, which is more urbanized and geologically distinct.

To apply the erosion rates developed for the East Branch of Soquel, a GIS road layer from the Santa Cruz County GIS database was used to determine the length of road coverage per analysis subwatershed (Figure 8). Additionally, a GIS road layer representing known dirt roads that exist within the Forest of Nisene Marks was digitized by the Coastal Watershed Council and utilized. To differentiate between roads that occur along the sensitive "inner gorge" of the stream valley and those further away from direct sediment input to the channel, a buffer was used to classify the road network. The buffer was varied by stream order with 1st order streams having a buffer of 50 feet, 2nd and 3rd order stream were given a buffer of 100 feet, and 4th order or greater streams were given a buffer of 150 feet. All roads occurring within this buffer were considered to be "inner-gorge" roads. All other roads were considered to be hillslope roads (Table 2).

Following separation of the roads into different classes, the total road mileage for each road class within each analysis subwatershed was calculated from the GIS database. Erosion rates from the Soquel Creek study were used to calculate the volume of sediment yielded from each of the four classes of roads in each subwatershed. Soils eroded from road features were designated as silty sand. Assuming that soils associated with road erosion features are moderately consolidated, the soil density was assumed to be 123.5lbs/ft^3 (Holtz and Kovacs, 1981).



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Aptos Creek Watershed
Location of Paved and Dirt Roads

Figure 8

Table 2: Sediment source yield estimates for road features in Aptos Creek Watershed.

Sediment Source	Sediment Yield from Soquel (CDF, 1993)	Sediment Yield assuming soil density is 123.5 lbs/ft^2
Paved Inner Gorge Roads	46.8 yd^3 mi^{-1} yr^{-1}	78 tons mi^{-1} yr^{-1}
Dirt Inner Gorge Roads	360 yd^3 mi^{-1} yr^{-1}	600 tons mi^{-1} yr^{-1}
Paved Hillslope Roads	46.8 yd^3 mi^{-1} yr^{-1}	78 tons mi^{-1} yr^{-1}
Dirt Hillslope Roads	360 yd^3 mi^{-1} yr^{-1}	600 tons mi^{-1} yr^{-1}

Other Lands

Erosion off of "other lands" is meant to be a catch-all category for sources associated with rilling, gullying, overland flow, or erosion from temporarily disturbed land or bare areas. Since this type of erosion is very difficult to measure without conducting a comprehensive study, sediment input from urban and rural lands was accounted for by utilizing sediment yield values from the study conducted on the East Fork of Soquel Creek (Cafferate and Poole, 1993). In the Soquel study, erosion from urban and rural land also included mass wasting. Since we already accounted for much of the mass wasting in our previous calculations, the erosion rate from the Soquel study was reduced to only reflect a sediment rate that does not include mass wasting sources. As in the case of the Zayante Area Sediment Study, the remaining amount associated with non-mass wasting sources from rural and urban lands was assumed to be 50% of the value reported in the Soquel study. At this time we cannot confirm if this is an accurate representation of the conditions present in the Aptos Creek Watershed but feel it is important to maintain consistency for the sake of comparing regional results.

Soils eroded from urban and rural lands were designated as silty sand. Assuming that soil eroded from urban and rural lands are moderately consolidated, the dominant soil density of these features is estimated to be 123.5lbs/ft^3 (Holtz and Kovac, 1981). Sub-watershed areas were estimated using the subwatershed GIS layer to calculate the sediment yield for each sub-watershed.

2.1.3 – Delivery Efficiency

Delivery efficiency is an important element of any sediment budget because it defines the proportion of sediment that actually makes it to the channel, as opposed to being deposited on the hillslope or the inside ditch of a road. The delivery efficiency of any specific grain is ultimately related to rainfall rates, length of the drainage pathways, and proximity of the sediment source to a waterway. The precise fate of any single grain of sediment is difficult to know, but general assumptions can be made about the delivery efficiency of a particular source class.

To maintain consistency with the Zayante Area Sediment Study and the San Lorenzo TMDL, we used identical delivery efficiencies for sediment sources in the Aptos Creek Watershed, if the information was available (Table 3). For landslides, it was assumed that the slide mass likely terminated at a stream channel, but given the fact that much of the material remains on the hillslope, a low delivery efficiency was assigned to this sediment source (20%). The toe of the slide mass will continually erode but this process is likely to occur over a period of several decades with much of the slide mass reestablishing vegetation and stabilizing. Conversely, bank failures likely result in 100% delivery of sediment to the active channel with very little material remaining perched for later delivery.

Table 3: Sediment delivery efficiencies for each sediment source.

Sediment Source	Sediment Delivery Efficiency
Mass Wasting	20%
Bank Erosion	100%
Inner Gorge Roads	100%
Hillslope Roads	42%
Urban and Rural Lands	42%

2.1.4 – Grain-size Analysis

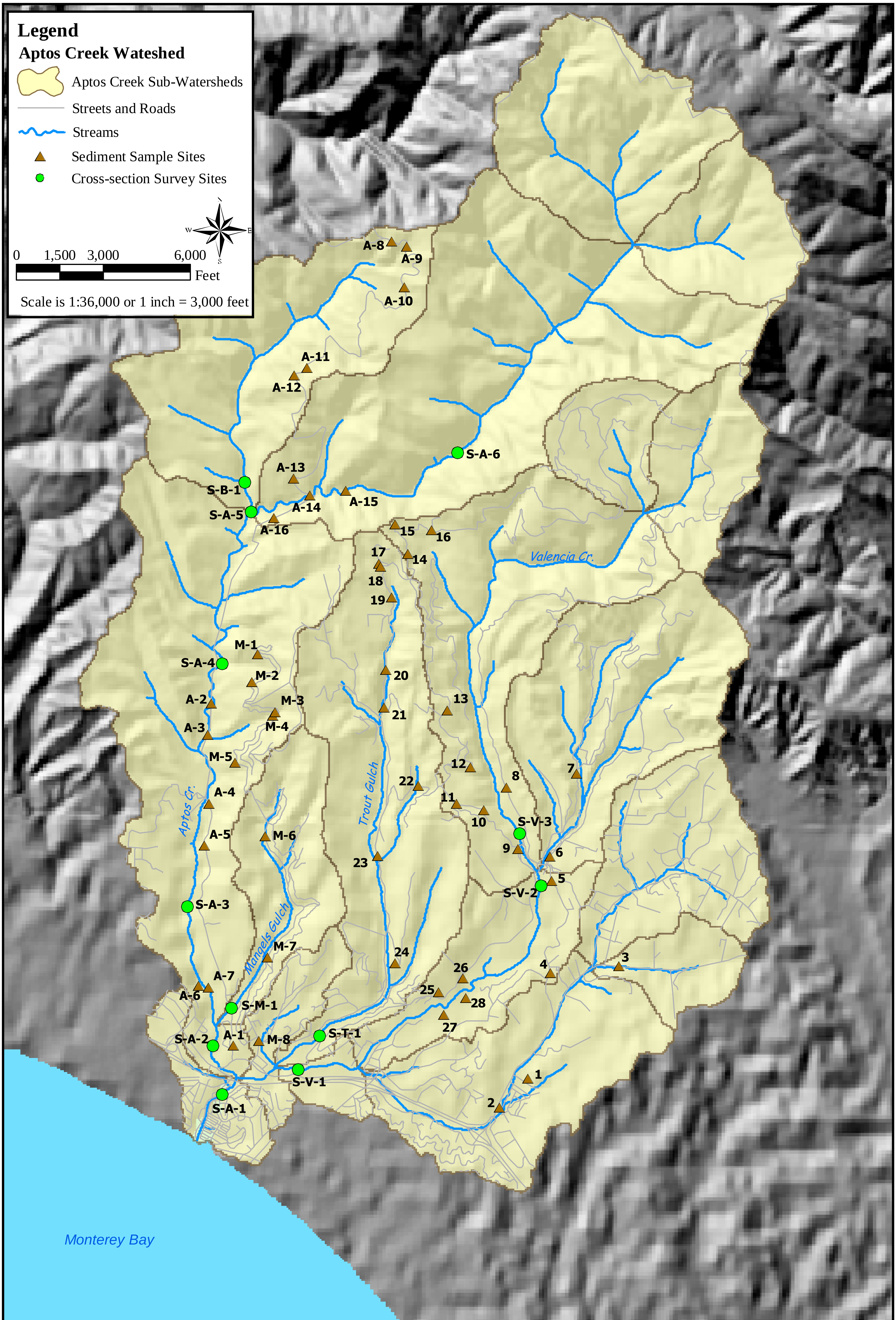
Though it is not essential to have grain-size information in order to estimate a sediment budget, grain-size from sediment sources in a watershed can provide important data regarding the type of sediment that is being delivered and how that sediment might be transported through the stream system. Given that the ultimate goal of this assessment is to determine the condition of aquatic habitat and the impact that fine-sediment input may be having on salmonid production, we felt it important to determine the proportion of fine sediment being eroded from the hillslopes and into the stream channel compared to the total mass of sediment.

To accomplish this, SH&G staff visited 52 sites throughout the Aptos Creek Watershed and collected sediment samples that were representative of the material being eroded from the site (Figure 9). The erosion sites were fairly well distributed across the landscape and included an even sample of all the types of erosion sources in the watershed including landslides, roadside ditches, exposed areas associated with construction sites, bank erosion areas, road cuts, and road shoulders. Sample locations were mapped on a USGS 1:24,000 quadrangle map. Collected samples were dried in an oven and a 100 mg subsample was sieved using a portable hand-held sieve. Sieve sizes of 1.7, 1.18, 0.85, and 0.6 millimeters were used in the analysis. The entire sample was retained in case more analysis of the sample is required in the future.

2.1.5 – Sediment Flux in Aptos Creek

A complete sediment budget requires information about the amount of sediment being delivered to the channel (I) as well as the amount of sediment being transported past the point of interest (O). Any imbalance between the input (I) and the output (O) is assumed to be the change in storage in the system (S). A positive storage value suggests that sediment is being stored in the channel through aggradation of the bed or is being stored in floodplain or bar deposits. A negative storage value suggests channel downcutting.

In order to estimate the Output term of the sediment budget equation, streamflow, suspended sediment, and bedload data must be available. The most often used data of this type is available from the U.S. Geological Survey (USGS) who maintain an extensive network of streamflow gages and water quality monitoring sites throughout the country. Unfortunately, many of the gages historically supported by the USGS have been abandoned due to budget cuts and a lack of interest in long-term hydrologic monitoring (Rodda, 1998). Water quality data, including periodic measurements of suspended and bedload, were not supported at all streamflow monitoring sites and, therefore, constitute a spotty dataset to begin with.



Swanson Hydrology and Geomorphology 115 Limekiln St. Santa Cruz, CA 95060 tel. 831-427-0288 fax. 427-0472	Aptos Creek Watershed Sediment Sample and Cross-section Survey Locations	Figure 9

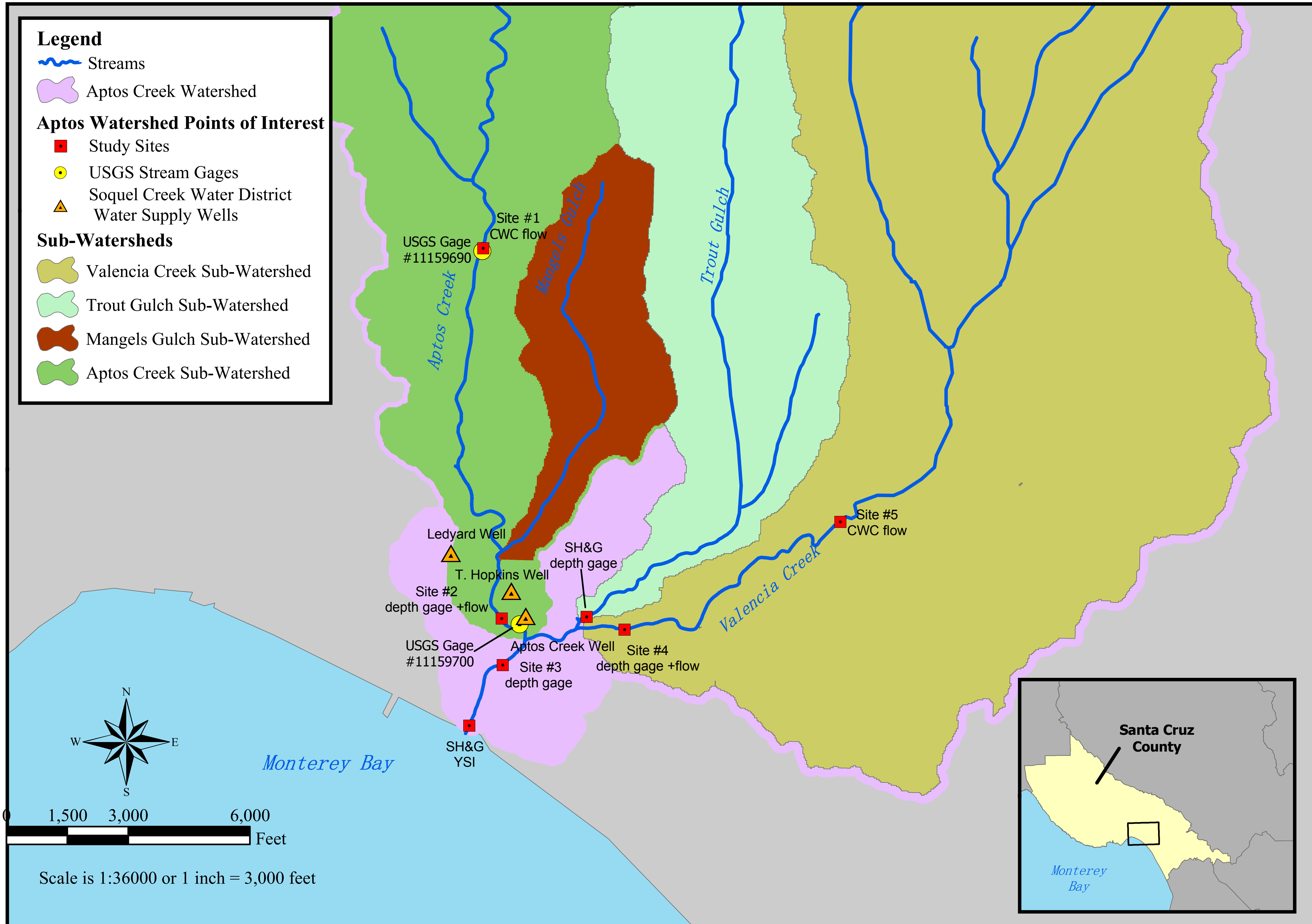
The USGS historically supported two streamflow gages on Aptos Creek, upstream of the Valencia Creek confluence (*see the Hydrology and Water Quality Technical Memorandum*). One gaging site was supported from 1959 to 1972 (Gage ID #11159700) and monitored a drainage area of 12.3 mi^2. The other site was supported from 1972 to 1985 (Gage ID #11159690) and monitored a drainage area of 10.2 mi^2. At both of these sites no water quality information was collected, except during a few low magnitude events. Each monitoring site was primarily equipped with a streamflow gage that provided a continuous record of average daily flow for the monitoring period.

As part of the hydrologic and water quality technical studies for the Aptos Creek Watershed Assessment, four temporary streamflow gages. The four sites consisted of water level recorders installed near the Spreckles Bridge, on Aptos Creek adjacent to the County Park, and on Valencia and Trout adjacent to the Valencia School for the 2002 Water Year (Figure 10). Along with water level and streamflow data, suspended sediment samples were collected periodically during the rainy season to determine suspended sediment concentrations (SSC) within each of the tributaries during peak flow events. A DH-49 depth integrating hand-held suspended sediment sampler was used at each site. Due to time constraints, only a single vertical, in the center of the channel, was collected at each site, and was assumed to be representative of the cross-section. Each sample was then taken back to a lab where it was filtered and weighed to determine the SSC.

From the SSC data collected at the County Park site on Aptos Creek (Site #2), we developed a rating curve relating SSC to discharge values obtained from the water level data collected at the site. Since W.Y. 2002 lacked high magnitude peak flow events, the rating curve only represents the lower, more linear portion of the SSC to discharge relationship. Due to the lack of information about the SSC of higher magnitude discharge events, we assumed linearity throughout the relationship. It is likely that this assumption underestimates the SSC for high magnitude discharge events. This underestimation may be partially balanced out by the fact that the data collected for peak events only included a single vertical in the center of the channel which may result in a higher assumed sediment concentration than if integrated over the entire cross-section. Rating curves were also developed for the Valencia and Spreckles Bridge sites to compare the differences in SSC with discharge at those sites. They were not used to generate estimated long-term sediment yields due to the lack of a long-term hydrologic data set.

To calculate a long-term sediment yield for the County Park site, streamflow data for USGS gage #11159700 was downloaded from the web. The data is provided by the USGS in units of cubic feet per second. Discharge for each day was converted to liters per day and multiplied by the SSC developed from the rating curve (in milligrams per liter) to produce an estimate of the total daily suspended sediment yield (in milligrams). Daily values were then added up for each year and converted to tons. The 14 years of data from 1972 to 1985 were averaged to produce an estimate of the average suspended sediment yield per year for the portion of the Aptos Creek Watershed that occurs upstream of the Valencia Creek confluence.

The main piece of missing information is lack of bed load data. We did not collect bedload data due to the difficulty and expense in doing so. Bed load conditions can vary considerable from one storm to the next, even given the same discharge values, so it becomes very problematic to develop a rating curve with much confidence. When lacking bed load information, it is common to estimate bed load as a percentage of suspended load. In streams with bed material dominated by coarse substrate such as gravel, cobble, and boulders, high



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discharge values are required to move a significant amount of material since the bed is often armored. In these cases, bed load is assumed to be approximately 10% of the suspended load. Aptos and Valencia Creek are dominated by fine and coarse-grained sand, which will move as bed load during lower magnitude events as sand waves. Because of this, we would expect bed load to be are larger proportion of the overall sediment load moving through these stream channels. To account for higher bed load movement, we have assumed that bed load would be approximately 25% of suspended load. For Valencia and Trout, this value may be higher.

2.2 – CHANNEL CONDITIONS

Once sediment is delivered to the stream, the grain-size of the material, channel morphology, and peak streamflow duration and frequency dictate how the sediment is going to be transported and sorted through the channel system. We developed a field approach to locally quantify some of these variables in order to understand how they interact and potentially control observed habitat conditions.

2.2.1 – Channel Cross-sections

Cross-sections were surveyed at all reaches established as part of the fisheries and geomorphic walk-through surveys. The cross-section locations were chosen to be representative of the reach as a whole at a location that was reasonably accessible (Figure 9). At each site, three cross-section were surveyed using an auto level, stadia rod, and measuring tape. A relative benchmark was established at each site with an elevation of 100’ in order to vertically associate each of the cross-sections. The three cross-sections were spaced so as to obtain an accurate estimate of the thalweg, water surface, and bankfull slope of the channel. This required an approximate distance of 100 to 200 feet between cross-sections. The longitudinal distance between each cross-section was measured with a tape.

2.2.2 – Pebble Counts

Bed material grain-size was estimated at each set of cross-sections by conducting a pebble count (Wolman, 1954). Approximately 200 pebbles were sampled on depositional features within the low flow channel. Depositional features were sampled to understand the grain-size distribution of sediment that would likely be mobilized during a peak flow event. A single pebble count was conducted for each group of 3 cross-sections. From the pebble count data, D16, D50, and D84 values were calculated. These values represent the 16^{th}, 50^{th}, and 84^{th}, cumulative percentile of the data, respectively, if the data is sorted from finer to larger material.

2.2.3 – Estimated Shear Stress

Shear stress is the primary hydraulic variable that is used to determine the size of bed material that can be moved and held in suspension during a particular discharge event. Shear stress is a function of water depth and water surface slope. Since depth is a variable in the calculation of shear stress, channel morphology plays an important role in determining the amount of flow that would be necessary to move a particular sediment grain from the bed. Wide channels with shallow depth will move smaller grain-sizes, given a constant flow, compared to a narrow channel that is deep. Relationships have been developed defining the critical shear stress required to move a range of grain sizes (Dunne and Leopold, 1976).

A dimensionless shear stress was calculated for each site for a range of discharges by inserting the cross-section data into a HEC-RAS model. The output from the HEC-RAS model consisted of water surface depths and slopes for each discharge event. This information was then used to calculate a dimensionless shear stress.

Once dimensionless shear stress values were calculated for each site for a range of flows, grain-sizes values that would be expected to move for each shear stress value were estimated (Dunne and Leopold, 1976). A curve was then produced for each site comparing the expected minimum diameter grain-size that would move in a given discharge event.

2.3 – WOODY MATERIAL DENSITIES

The occurrence of large woody material within the active channel has been shown to be positively correlated with high quality salmonid spawning and rearing habitat. Woody material improves habitat conditions by providing important roughness elements to induce pool formation, clean gravels by generating hydraulic variability, and places to hide from predators and damaging high flow events. Woody material also provides a surface and nutrient source to support macroinvertebrate communities, a preferred food source for juvenile salmonids.

During the fisheries and geomorphic walk-through surveys, we quantified woody material densities continuously along all surveyed reaches. Individual logs, rootwads, and organic debris jams were surveyed using a method outlined in the California Stream Habitat Restoration Manual developed by the California Department of Fish and Game (Flosi and Reynolds, 1998). An example of the data sheet is presented in Appendix A. Along each reach the following information was collected:

- Sample length (collected using a hip chain)
- Starting and ending point of each surveyed segment
- Rosgen channel type
- Dominant canopy vegetation
- The number of logs, rootwads, or jams that occurred within the active channel according to the following size classes:

1-2' Diameter	2-3' Diameter	3-4' Diameter	> 4' Diameter	Debris Jams (LDA's)
Logs 6-20' in length	Logs 6-20' in length	Logs 6-20' in length	Logs 6-20' in length	# of large pieces in debris jams were estimated
Logs > 20' in length	Logs > 20' in length	Logs > 20' in length	Logs > 20' in length	
Rootwad	Rootwad	Rootwad	Rootwad	

Additional information was collected about each piece surveyed including weather the piece was dead and downed, dead and standing, or live. Live pieces were categorized into either deciduous or coniferous. Woody material data collected for each reach was compiled and the number of pieces per mile for each category was calculated to allow for comparisons between each reach. Results from certain reaches may be underestimated if a large portion of the material occurred in debris jams, as these were not separated into their individual categories due to the difficulty of estimating the number and size of material in the field.

2.4 – Identification of Significant Erosion Sources

Our sediment budget analysis primarily focused on general sources of sediment to the stream channel at a subwatershed level and did not focus on discrete sources. Additionally, the sediment budget included sources that were both natural and anthropogenic without regard for their treatment potential or direct impact on salmonid habitat quality. To improve habitat conditions in the future by reducing the amount of fine sediment that is directly delivered to the channel, it is necessary to identify discrete sources of chronic fine sediment and develop an approach and plan to treat them.

The most effective way of identifying chronic and problematic sediment sources is to physically map them from the ground. In some landscapes, high-resolution aerial photos could prove to be an effective way of identifying problems, but in the case of the Aptos Creek Watershed, dense tree cover reduces the observers' ability to identify all but the most egregious sources.

To identify sources in the Aptos Creek Watershed, SH&G staff drove all publicly accessible roads in the watershed, including the dirt road that runs through the Forest of Nisene Marks State Park to the ridgeline with Soquel Creek. Significant sediment sources were identified and mapped on a USGS 1:24,000 quadrangle and included in a GIS database. Information collected at each site included:

- A site ID,
- Which subwatershed the source occurred in,
- A detailed description of the source location,
- The perceived cause of the erosion problem,
- Historical context of the site such as information regarding previous attempts to repair the site,
- The size of the erosion site (length, width, depth),
- An erodibility index from 1-10 to describe the severity of the problem,
- A preliminary description of the corrective measures that could be implemented at the site to improve conditions and reduce erosion,
- A photo of each site, and
- A sediment sample was taken at selected sites to describe the grain-size distribution of eroding materials. The methods for this approach are included in Section 2.1.4.

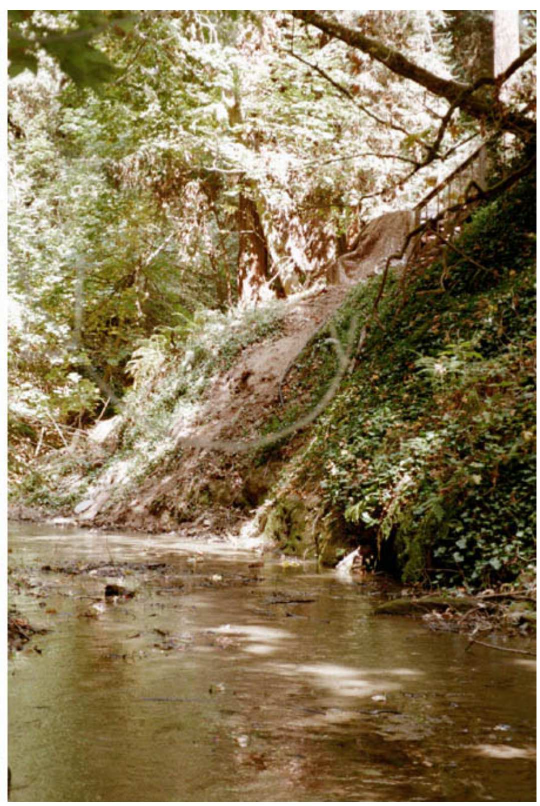
3.0 – RESULT AND DISCUSSION

3.1 – SEDIMENT BUDGET

3.1.1 - Sediment Input (I)

The primary purpose of the sediment budget estimate that we have put together for this report is to understand the dominant erosion processes that are occurring in the watershed, what the relative magnitude of each of those might be, and which portions of the watershed are contributing to the overall sediment budget. It is not intended to quantify and understand the fate of each grain of sand being delivered to the channel. Instead, it is meant to direct attention to specific sources as a way to focus future efforts to control erosion in the watershed in an intelligent and informed way.

Table 4 lists the estimated sediment yield for the Aptos Creek Watershed by sediment source and location. The total estimated sediment yield for the Aptos Creek Watershed is approximately 60,000 tons/year. Averaged over the whole watershed, the expected yield is approximately 2,440 tons/mi^2/year. Each subwatershed has an expected yield of 2,660, 2,330, 3,060, and 2,040 tons/mi^2/year for Aptos, Mangels, Trout, and Valencia, respectively. These values fall within the expected range of sediment yields generated for other watersheds in coastal California (Table 5). Sediment yields from other forested watersheds range from 5,486 tons/mi^2/year in Redwood Creek to 680 tons/mi^2/year on the South Fork of Caspar Creek.

Mass wasting on Aptos and Valencia Creeks. Both are chronic sediment sources. The one on the left appears to be natural, caused by undercutting in the outer bend of a meander. The photo on the right is clearly related to development occurring at the top of the hillslope.

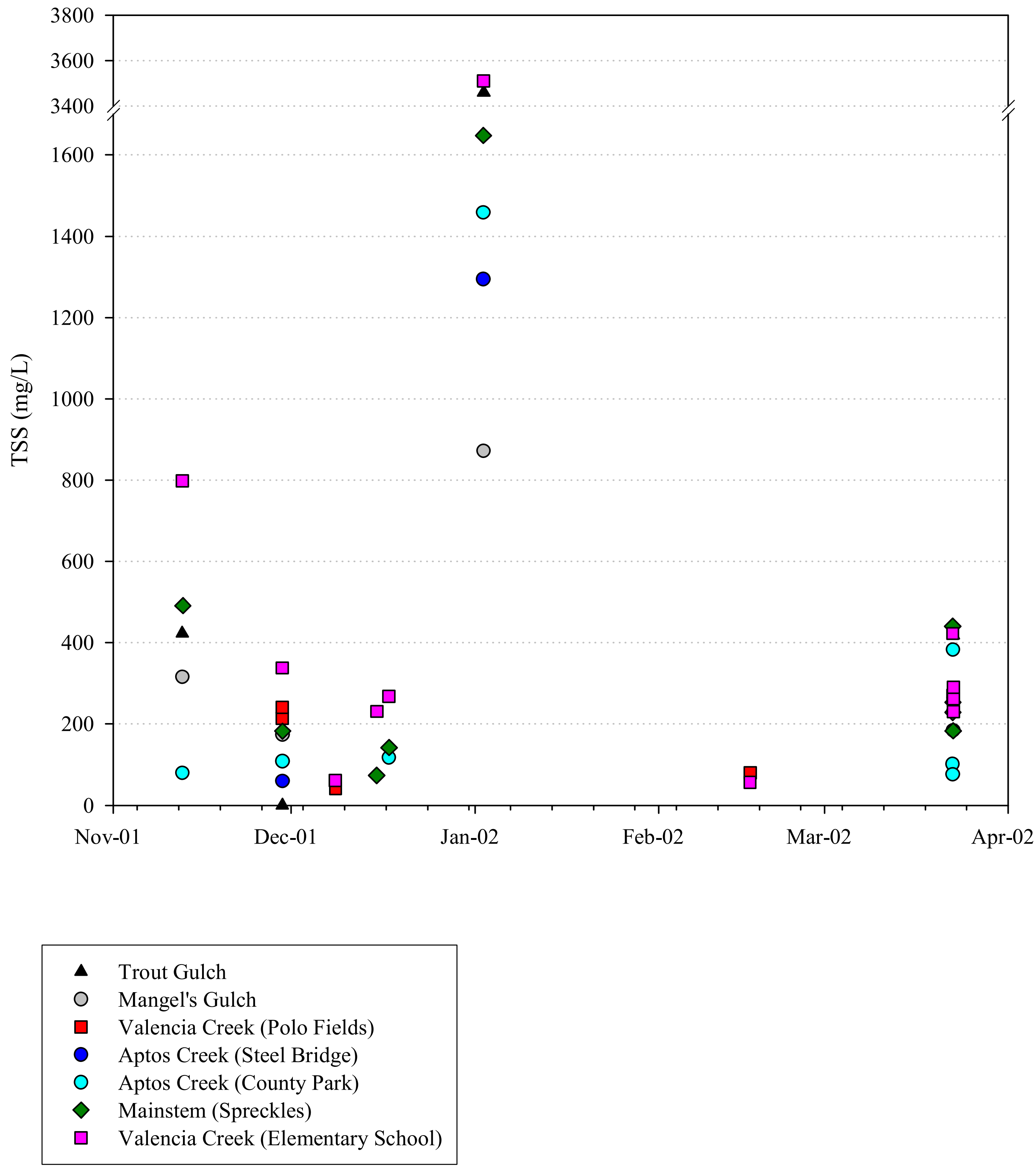
	Sub-Watershed	Feature Length (miles)	Erosion Rate (tons/mi^2/yr)	Delivery Efficiency	Sediment Delivery Rate to Streams (tons/mi/yr)	Sediment Yield (tons/yr)	Totals by Erosion Type (tons/yr)	Total Sediment Yield (tons/yr)	Total Sediment Yield (tons/mi2/yr)
Inner Gorge Paved Roads	Aptos Creek	3.4	78.1	100%	78.1	263	1,293	**59,978**	**2,442**
	Mangels Gulch	2.0	78.1	100%	78.1	159			
	Trout Gulch	1.8	78.1	100%	78.1	143			
	Valencia Creek	9.3	78.1	100%	78.1	728			
Inner Gorge Dirt Roads	Aptos Creek	1.6	600	100%	600	560	581		
	Mangels Gulch	0.1	600	100%	600	21			
	Trout Gulch								
	Valencia Creek								
Hillslope Paved Roads	Aptos Creek	23.6	78.1	42%	33	773	4,052		
	Mangels Gulch	13.8	78.1	42%	33	452			
	Trout Gulch	14.1	78.1	42%	33	463			
	Valencia Creek	72.1	78.1	42%	33	2364			
Hillslope Dirt Roads	Aptos Creek	6.0	600	42%	252	1523	1,566		
	Mangels Gulch								
	Trout Gulch								
	Valencia Creek	0.2	600	42%	252	43			
Bank Erosion	Aptos Creek	24.7	70	100%	70	1729	8,184		
	Mangels Gulch	2.1	170	100%	170	357			
	Trout Gulch	6.0	327	100%	327	1962			
	Valencia Creek	21.1	196	100%	196	4136			
	Sub-Watershed	**Feature Area (Sq. miles)**	**Erosion Rate (tons/mi^2/yr)**	**Delivery Efficiency**	**Sediment Delivery Rate to Streams (tons/mi^2/yr)**	**Sediment Yield (tons/yr)**			
Mass Wasting	Aptos Creek	11.6	8449	20%	1690	19587	30,791		
	Mangels Gulch	1.2	4868	20%	974	1197			
	Trout Gulch	2.3	7025	20%	1405	3271			
	Valencia Creek	9.4	3580	20%	716	6736			
Urban and Rural Lands	Aptos Creek	11.6	1310	42%	550	6378	13,511		
	Mangels Gulch	1.2	1310	42%	550	676			
	Trout Gulch	2.3	1310	42%	550	1281			
	Valencia Creek	9.4	1310	42%	550	5176			

Table 4: Estimated sediment yield for each erosion source, by major subwatershed.

Table 5 : Published Annual Sediment Yields for the Coast Ranges of California. Note data was obtained from the Zayante Area Sediment Source Study (Swanson and Dvorsky, 2001).

River/Stream	Sediment Yield (tons/mi^2)	Watershed Area (mi^2)	Period of Record	County
Redwood Creek	4750	278	1954-1997	Humboldt
Redwood Creek	5485	278	1954-1997	Humboldt
Garcia River	1400	114	1952-1997	Mendocino
South Fork Caspar Creek	680	1.83	1962-1998	Mendocino
North Fork Caspar Creek	1111	1.64	1962-1998	Mendocino
Navarro River	1200	303	1980-1988	Mendocino
Arroyo Grande Creek	380	13.5	1943-1972	San Luis Obispo
Lopez Creek	1800	21.6	1943-1972	San Luis Obispo
Santa Rita Creek	1100	18.2	1943-1972	San Luis Obispo
Uvas Creek	1337	21	1967-1969	Santa Clara
Coyote Creek	813	109	1967-1969	Santa Clara
Arroyo Valle	1000	147	1967	Contra Costa
Colma Creek	6768	10.8	1966-1970	San Mateo
Little Santa Anita Canyon	22262	2.4	1938, 43, 52	Los Angeles
Pickens Canyon	43069	1.7	1938, 43, 54	Los Angeles

Surprisingly, the sediment budget results suggest that Valencia has the lowest per unit sediment yield despite the fact that it is the most turbid tributary during peak discharge events (Figure 11) and has a bed primarily composed of sand that overwhelms the stream and contributes to degradation of aquatic habitat. The sediment budget results may not completely describe what is occurring both in Valencia and Trout. What is missing from our sediment budget analysis is an estimate of the amount of sediment that has historically been delivered to the channel and is in the process of being reworked and remobilized. Fine sediment deposits stored in the channel and in the floodplain, potentially due to turn of the century logging, may be remobilized under most flow conditions, due to the sandy nature of the deposits, and result in a higher sediment yields than would be expected based on our estimate of erosion from hillslope and bank erosion.



Swanson Hydrology & Geomorphology 115 Limekiln Street Santa Cruz, CA 95060 tel: 831.427.0288 fax: 831.427.0472	TSS sample data collected for each main tributary in the Aptos Creek Watershed.	Figure 11

Shallow sandy bed on Valencia Creek.

Valencia and Trout may also be significantly impacted by recent urbanization of the watershed which has had a cumulative impact on the conditions in the channel. As watersheds urbanize, an increasing percentage of the land surface becomes impervious to rainfall due to more roads, rooftops, and driveways. The increase in impervious surfaces creates a hydrologic regime that is flashier, with higher peak flow values. This is especially evident during low magnitude precipitation events. In undisturbed watersheds, low magnitude precipitation events produce very little runoff due to soil storage and percolation to groundwater. In urbanized watersheds, even small amounts of rainfall produce a significant amount of runoff from impervious surfaces that are delivered quickly to stream channels. This has been shown to increase bank erosion (Booth and Henshaw, 2001) and create unstable geomorphic conditions as the channel attempts to adjust to a new hydrologic regime.

This process is magnified as the watershed becomes increasingly urbanized. There is little time for the channel to adjust to changing hydrologic conditions if those conditions are continually changing. When a channel is in a continual state of change, a massive disturbance episode could result in catastrophic consequences. According to anecdotal evidence, it appears that such a scenario occurred on Valencia and Trout Creeks in the wake of the 1982 flooding event. Prior to 1982, the Valencia and Trout Creek watershed were experiencing periods of fairly rapid urbanization, especially during the 1970's. At that time, very few people considered the repercussions development would have on the stream channels and aquatic habitat conditions. Fisheries conditions in Valencia appeared to remain fairly stable, despite the impacts occurring in the watershed. In 1980, a comprehensive estimate of steelhead numbers and habitat quality was conducted throughout Santa Cruz County (Smith, 1982). The data suggest that Valencia supported a good steelhead fishery. In fact, Valencia had some of the highest densities of juvenile steelhead in Santa Cruz County.

In the winter of 1982 a series of storms battered the California coast, causing extensive damage throughout Santa Cruz County. These storms may have been the "straw that broke the camels back" for Valencia Creek, an event that the system has yet to recover from. Eyewitnesses reported severe damage to Valencia Creek that included complete unraveling of the banks of the lower stream channel and 2 to 5 feet of aggradation that consisted almost entirely of sand-sized material (Smith, personal communication). If this is true, it is likely that the system is still adjusting to such a massive sedimentation event while at the same time reacting to increased pressure from urbanization and a continually changing hydrologic regime. If we were to assume that 3 feet of aggradation occurred over a total distance of 7 miles along the mainstem reaches of Valencia and Trout Creek, with an average floodplain width of 20 feet (assuming sediment deposited directly in the channel was removed soon after the aggradation event), there would be approximately 98,000 tons of sediment available for transport. That amount is approximately 4 times the estimated volume of sediment delivered to Valencia and Trout Creeks from all other sources combined (Table 6). This sediment source should be investigated in the future in order to refine our preliminary sediment budget estimates.

Table 6: Estimates of natural versus anthropogenic sediment yields from Aptos Creek Watershed.

Subwatershed	Sediment Yield (tons/yr)	Sediment Yield (tons/mi2/yr)	Natural (tons/yr)	Athropogenic (tons/yr)
Aptos	30,813	2,658	22,505	8,308
Mangels	2,862	2,328	1,747	1,115
Trout	7,120	3,058	2,759	4,361
Valencia	19,183	2,039	8,105	11,078

The sediment budget numbers can also be manipulated to obtain a rough estimate of the amount of material that is being delivered to the stream channel from either natural or anthropogenic sources (Table 6). This requires some knowledge of the land uses occurring in a particular subwatershed and an educated estimate of the percent of the total yield that is expected to be caused by human impacts, as opposed to naturally occurring erosion processes. Table 7 outlines the percentages that were determined to be appropriate for each source for each individual watershed. Sediment delivered to the channel off of roads was assumed to be entirely anthropogenic, whereas the other categories were proportioned according to observed land use impacts in the watershed. Aptos was assumed to be the least influenced by human interactions to the landscape. Much of the watershed is protected within a state park and a large number of the landslides occurring within the watershed have been documented to be a result of the Loma Prieta earthquake.

Table 7: Percent of erosion that was considered to be anthropogenic for each erosion source.

Subwatershed	Erosion from Roads	Bank Erosion	Mass Wasting	Urban and Rural Lands
Aptos	100%	30%	30%	30%
Mangels	100%	50%	50%	50%
Trout	100%	70%	60%	80%
Valencia	100%	70%	60%	80%

The results from this rough analysis suggest that a significant proportion of the sediment being delivered to Trout and Valencia Creek are due to anthropogenic sources and could potentially be reduced through better erosion control practices, implementation of Best Management Practices (BMP's) that address specific problems that occur within those watersheds, and potentially, stabilization of hydrologic conditions by increasing soil infiltration and retaining or detaining runoff from impervious surfaces. Sediment reductions on the order of 20 to 50% of existing yields could improve aquatic habitat conditions considerably. The upper watershed of Aptos Creek provides high quality spawning and rearing habitat for salmonids despite a significant amount of fine sediment being delivered to the channel.

3.1.2 - Sediment Output (O)

Since an extended streamflow record is limited to Aptos Creek, upstream of the confluence with Valencia, we were only able to estimate the sediment output term (O) for that portion of the watershed. The rating curve developed for the Aptos Creek site is shown in Figure 12. The rating curve was used along with the historic streamflow record from Aptos Creek (1972 to 1985) to estimate suspended sediment transported through Aptos Creek (Table 8). Bedload was assumed to be 25% of the suspended sediment load. The results suggest that approximately 25,000 tons of sediment is being transported through Aptos Creek upstream of the confluence with Valencia. This value is fairly close to the 30,800 tons of sediment that was estimated as being delivered to Aptos Creek from the watershed.

Considering that a portion of the sediment eroded from the watershed is coarser material that may be stored in gravel and cobble bars (Table 9) and a portion is stored behind the extensive logjams that occur in the upper watershed, we feel these numbers correspond fairly well. Additionally, the rating curve, developed to estimate the suspended portion of the sediment load, is likely to underestimate the amount of sediment being moved during larger events since our sampling was limited to fairly low magnitude events. Generally, we feel comfortable with the results given the amount of data available to construct the sediment budget and the assumptions that needed to be made to arrive at a final estimate. It is not uncommon for sediment budget calculations to be an order of magnitude off given the challenges inherent in sediment budget calculations and a requirement to make general assumptions regarding the processes that are at work in the watershed controlling both delivery and transport of sediment to and through the system.

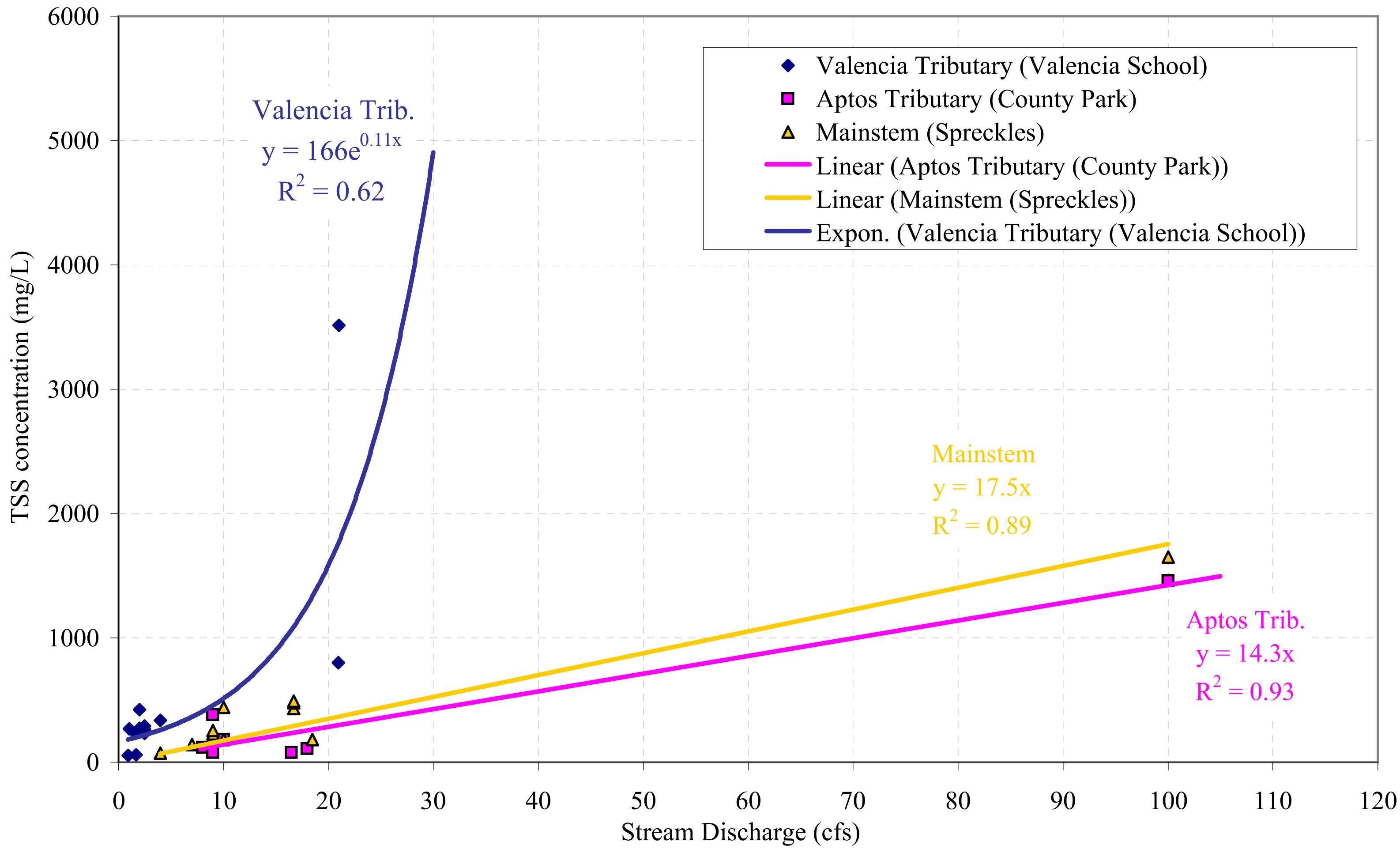


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Figure 12: Discharge to total suspended sediment concentration rating curves developed for Mainstem Aptos Creek, Aptos Tributary, and Valencia Tributary.

Table 8: Estimated suspended and bedload transport through Aptos Creek based on field measurements and historic streamflow records. Also shown is the estimated sediment input for the Aptos subwatershed based on the sediment budget analysis.

Water Year	**Annual Suspended Sediment Yield**		**Suspended + Bedload (bedload estimated as 25% of Suspended)**
	in grams	in tons	in tons
1959	3.23E+09	3,562	4,453
1960	1.38E+09	1,525	1,906
1961	4.31E+07	48	59
1962	5.18E+09	5,708	7,135
1963	5.49E+10	60,532	75,665
1964	7.82E+08	862	1,078
1965	1.32E+10	14,527	18,159
1966	1.32E+08	146	182
1967	2.48E+10	27,322	34,153
1968	1.85E+09	2,041	2,551
1969	2.99E+10	32,912	41,140
1970	2.48E+10	27,357	34,196
1971	1.11E+09	1,219	1,524
1972	9.92E+07	109	137
1973	2.82E+10	31,108	38,885
1974	1.09E+10	11,980	14,975
1975	3.86E+09	4,257	5,322
1976	5.11E+07	56	70
1977	2.20E+07	24	30
1978	1.61E+10	17,724	22,155
1979	1.39E+09	1,535	1,919
1980	3.26E+10	35,904	44,879
1981	1.07E+09	1,182	1,477
1982	1.81E+11	199,907	249,884
1983	5.79E+10	63,852	79,816
1984	7.21E+09	7,955	9,943
1985	1.49E+09	1,638	2,047
Average	**1.86E+10**	**20,555**	**25,694**
Estimated Sediment Input to Aptos			**30,813**

Table 9: Erosion sites sampled within the Aptos Creek watershed. Samples were collected using a shovel and dried and seived in the lab. Samples are meant to describe the grain-size distribution from characteristic erosion sources found in the watershed.

Sample ID	Sub-Watershed	Cause of Erosion	Erosion Site Id	Site Description	Sieve # / Sieve Opening				
					12	16	20	30	>30
					1.7mm	1.18mm	.85mm	.6mm	<.6mm
1	Valencia Creek	Landslide	25	Gully formed in sandy hillside near Aptos High School (See Site 25)	0	0	>11	50	50
2	Valencia Creek	Roadside Ditch		Bank erosion on Roadside Ditch; Sabina Way just N. of Hwy 1 on Freedom Blvd.	2	1	2	20	75
3	Valencia Creek	Roadside Ditch	18	Incised road ditch on Freedom Blvd (See description on Site 18)	1	0	1	25	73
4	Valencia Creek	New Development		New road construction on Valencia Rd. 100 feet N. of Huntington Intersection.	5	0	0	5	90
5	Valencia Creek	Tilled Orchard		2760 Valencia Rd.; several acres of tilled topsoil	5	1	2	17	75
6	Valencia Creek	Landslide	19	260 Cox Rd. on East side	3	0	2	15	80
7	Valencia Creek	New Development	20	Road cut across stream bed; 801 Bear Valley Way	1	1	3	25	70
8	Valencia Creek	Dirt Road		Flume Rd. after new drain rock section	10	10	12	13	55
9	Valencia Creek	Road Cut		Valencia School House Rd. at intersection with Valencia Rd.	1	1	3	10	85
10	Valencia Creek	Road Drainage		Mile 1.23 on Valencia School House Rd.; at culvert mouth.	1	0	0	9	90
11	Valencia Creek	Tilled Orchard		At Valencia School House intersection with Fern Flat rd.	1	0	0	0	99
12	Valencia Creek	Dirt Road		Dirt road off Fern Flat.	10	5	15	25	45
13	Valencia Creek	Landslide	16	Fern Flat Rd.; 1.5 miles S. of Trout Gulch intersection, (See Site 16 description)	20	5	5	20	50
14	Valencia Creek	Road Cut	22	Fern Flat Rd; .3 miles N. of Trout Gulch intersection.	2	0	0	8	90
15	Valencia Creek	Dirt Road		Fern Flat Rd.; 1.5 miles N. of Trout Gulch intersection.	65	1	2	7	25

Table 9: Erosion sites sampled within the Aptos Creek watershed. Samples were collected using a shovel and dried and seived in the lab. Samples are meant to describe the grain-size distribution from characteristic erosion sources found in the watershed.

Sample ID	Sub-Watershed	Cause of Erosion	Erosion Site Id	Site Description	Sieve # / Sieve Opening				
					12	16	20	30	>30
					1.7mm	1.18mm	.85mm	.6mm	<.6mm
16	Valencia Creek	New Development		753 Fern Flat Rd.; several acres of cleared and tilled hillslope.	3	1	1	10	85
17	Trout Creek	Perched Culvert		Two perched culverts that route Trout Gulch under Trout Gulch Rd. (4444 Trout Gulch Rd.)	5	1	3	6	85
18	Trout Creek	Road Cut		Failing road cut at 4444 Trout Gulch Rd. (Creek Crossing)	0	0	5	10	85
19	Trout Creek	Annual Tributary		Bank erosion on annual tributary; Trout Gulch Rd.	2	1	5	45	47
20	Trout Creek	Perched Culvert		Spring fed culvert on Trout Gulch Rd.; 3.44 mile marker.	5	0	0	45	50
21	Trout Creek	Bank Erosion		Small scale landslide on stream bank; 3555 Trout Gulch Rd.	2	1	2	60	35
22	Trout Creek	Incised Tributary	14	Down-cutting tributary converging with roadside ditch; .5 miles up Valencia School House Rd. (See site 14 description)	1	<1	1	10	88
23	Trout Creek	Culvert/ Tributary		Deposit from culvert at tributary confluence; 2225 Trout Gulch Rd.	0	0	1	80	19
24	Trout Creek	Bank Erosion/ Landslide		Left bank landslide 30ft. Wide by 25 ft. High; 1717 Trout Gulch Rd.	1	1	2	5	91
25	Valencia Creek	Road Cut	17	Unstable roadcut; 980 Valencia Rd.	2	0	3	5	90
26	Valencia Creek	Exposed Area		Several acres of tilled exposed dirt/ orchard; 1399 Valencia Rd.	5	0	0	5	90
27	Valencia Creek	Bank Erosion		Undercut right bank	10	2	3	15	70
28	Valencia Creek	Bank Erosion		Left bank failing upstream of log jam.	0	0	0	5	95
A-1	Aptos Creek	Exposed area		Very large parking lot area, (400ft. by 150ft.)	25	2	3	10	60

Table 9: Erosion sites sampled within the Aptos Creek watershed. Samples were collected using a shovel and dried and seived in the lab. Samples are meant to describe the grain-size distribution from characteristic erosion sources found in the watershed.

Sample ID	Sub-Watershed	Cause of Erosion	Erosion Site Id	Site Description	Sieve # / Sieve Opening				
					12	16	20	30	>30
					1.7mm	1.18mm	.85mm	.6mm	<.6mm
A-2	Aptos Creek	Landslide/ timber		Large landslide from logging/ roadcut, just below closed gate, (400ft. by 50ft.).	<1	<1	10	25	65
A-3	Aptos Creek	Landslide		Large landslide from roadcut, (40ft. by 40ft.).	40	5	5	10	40
A-4	Aptos Creek	Runoff		Runoff from parking area/ picnic area/ road just below steel bridge, (Area approx. 100 sq ft.).	15	5	20	40	20
A-5	Aptos Creek	Exposed shoulder		Loose dirt on exposed shoulder, (50 ft. long), bike induced in places.	60	<1	5	10	25
A-6	Aptos Creek	Bank Erosion		Old sediment deposit now on outside of bend eroding	<1	<1	<1	<1	97
A-7	Aptos Creek	Bank Erosion		Steep bank undercutting at bankfull	28	2	10	40	20
A-8	Aptos Creek	Gutter/ ditch		Near sand point, runoff from road above large culvert.	<1	<1	<1	5	95
A-9	Aptos Creek	Landslide/ road		Landslide from roadcut, (50ft. by 20ft.).	5	<1	10	20	65
A-10	Aptos Creek	Runoff/ gutter		Junction of Sand Point Trail and Big Slide Trail runoff from road.	0	0	5	10	85
A-11	Aptos Creek	Culvert		Outlet of culvert after much road runoff.	1	0	1	13	85
A-12	Aptos Creek	Road cut		Large landslide from roadcut, (50ft. by 30ft.).	0	<1	10	15	75
A-13	Aptos Creek	Runoff		Runoff from long gully stretch.	10	5	10	25	50
A-14	Aptos Creek	Culvert		Bank erosion caused by culvert above. Just below stream crossing/ drive through.	10	5	5	10	70
A-15	Aptos Creek	Bank erosion		Bank eroding due to stream/ trail, (30ft. by 8ft.).					
A-16	Aptos Creek	Roadcut		(40ft by 40ft.)	20	5	5	10	60

Table 9: Erosion sites sampled within the Aptos Creek watershed. Samples were collected using a shovel and dried and seived in the lab. Samples are meant to describe the grain-size distribution from characteristic erosion sources found in the watershed.

Sample ID	**Sub-Watershed**	**Cause of Erosion**	**Erosion Site Id**	**Site Description**	**Sieve # / Sieve Opening**				
					12	**16**	**20**	**30**	**>30**
					1.7mm	**1.18mm**	**.85mm**	**.6mm**	**<.6mm**
M-1	Mangels Gulch	Road cut		50ft. of road cut 6ft. high adjacent road taken from gutter; at end of road near 3637	55	<1	5	10	30
M-2	Mangels Gulch	Road cut		exposed sandstone 20ft. by 5ft.	<1	<1	10	20	70
M-3	Mangels Gulch	Dumped		Appears to be dumped along road embankment, (15ft. by 10ft.); adjacent to road across from small green water tank.	20	<1	10	25	45
M-4	Mangels Gulch	Landslide/ roadcut		Landslide induced by road cut, (30ft. by 20ft.)	8	2	20	35	35
M-5	Mangels Gulch	Road runoff		Sample taken from gutter/ ditch near school bus turn around					
M-6	Mangels Gulch	Culvert		Deposit at culvert outlet	35	<1	10	25	30
M-7	Mangels Gulch	Construction		Large sediment pile, (100ft. by 50ft.) covered from construction of new house.	20	2	3	15	60
M-8	Mangels Gulch	Exposed area		BMX park, mostly exposed, (100ft. by 100ft.) adjacent large parking lot/ drive, (300ft. by 50ft.).	10	2	3	25	60

3.2 – CHANNEL CONDITIONS

3.2.1 - Substrate Conditions

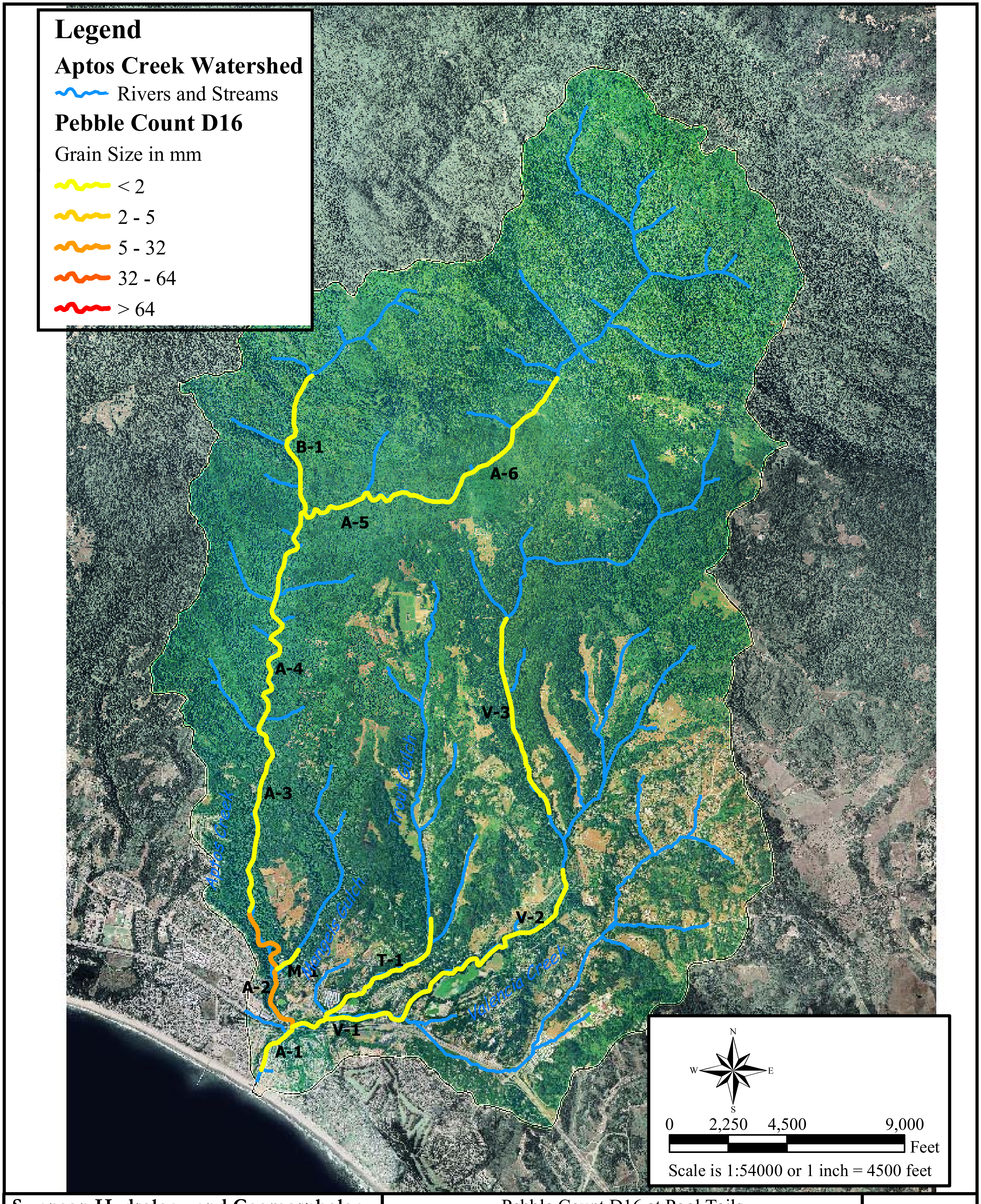
Channel conditions throughout the watershed are clearly shown in the pebble count results available at monitoring sites throughout the watershed (Table 10; Appendix B; Figures 13-16). Fine sediment is present throughout the watershed as evidence by the low D16 values and high percentage of fine material. The most degraded reaches include lower Aptos, below the confluence with Valencia, Trout, Mangels, and Valencia.

The cross-section and pebble count surveys were conducted in the fall months following a few low magnitude rainfall events, resulting in observations of coarser sediment than was present during the summer months when much of coarser substrate is buried under sand deposits. We observed this situation during several other field visits following storm events. Small pools are carved out near roughness elements and coarser material is exposed on the bed, only to be filled with sand-sized material as waves of fine-grained material moves through the system.

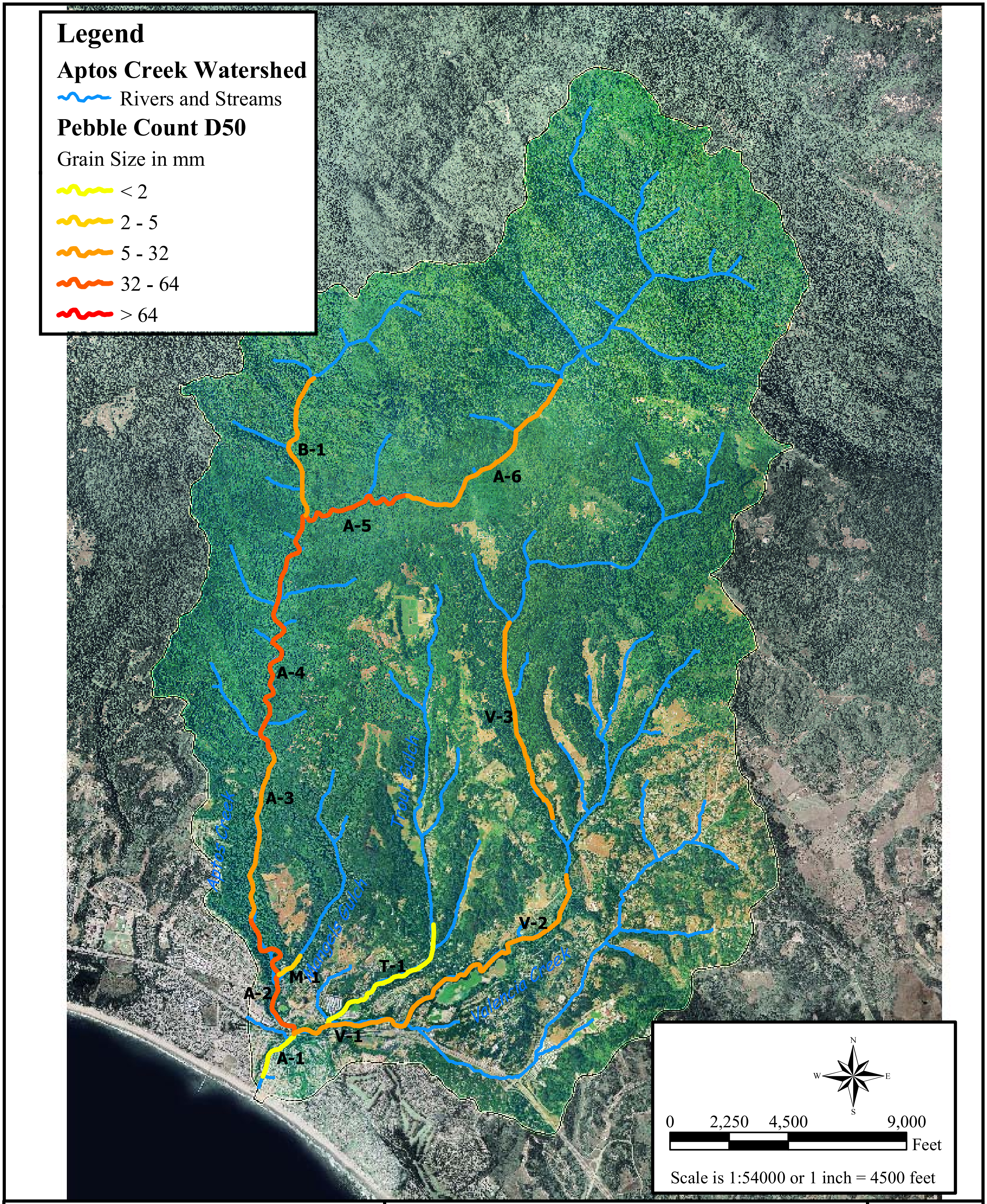
This phenomenon is evident in the calculations that were made to estimate the size of sediment that can potentially move under a range of flow conditions based on channel geometry and grain-size information available for each cross-section site. In lower Aptos, Mangels, Trout, and a few reaches of Valencia, the bed is mobile during even low to moderate discharges. This information clearly shows the difficulty of maintaining high quality spawning and rearing habitat in these tributaries under current conditions. A highly mobile bed, combined with a significant quantity of fine-grained sediment moving through the stream channel, precludes use of the stream channel for successful spawning. Even if spawning were to occur, rearing habitat appears to be limited.

Table 10: Pebble count results for monitored cross-sections throughout the Aptos Creek Watershed expressed as a percentile of the sample. An approximate flow at which the 50^{th} percentile of the sample is mobilized is also shown based on hydraulic modeling results. A more detailed presentation of the results is available in Appendix B.

Reach-ID	D16	D50	D84	Percent Fines (< 2 mm)	Approximate flow required to move D50
A-1	1.0	1.0	1.0	98	3 cfs
A-2	30.0	55.0	100.8	0	> 200 cfs
A-3	1.0	11.0	46.2	30	35 cfs
A-4	1.0	34.5	77.1	29	175 cfs
A-5	1.0	55.5	115.2	19	130 cfs
A-6	1.0	25.0	58.0	17	5 cfs
B-1	1.0	22.0	62.3	26	40 cfs
V-1	1.0	10.0	40.2	39	10 cfs
V-2	1.0	15.5	52.5	37	30 cfs
V-3	1.0	9.5	40.3	39	3 cfs
T-1	1.0	1.0	6.2	77	< 1 cfs
M-1	1.0	3.0	16.0	49	< 1 cfs



Swanson Hydrology and Geomorphology 115 Limekiln St. Santa Cruz, CA 95060 tel. 831-427-0288 fax. 427-0472	Pebble Count D16 at Pool Tails Aptos Creek Watershed Assessment and Enhancement Plan	Figure 13



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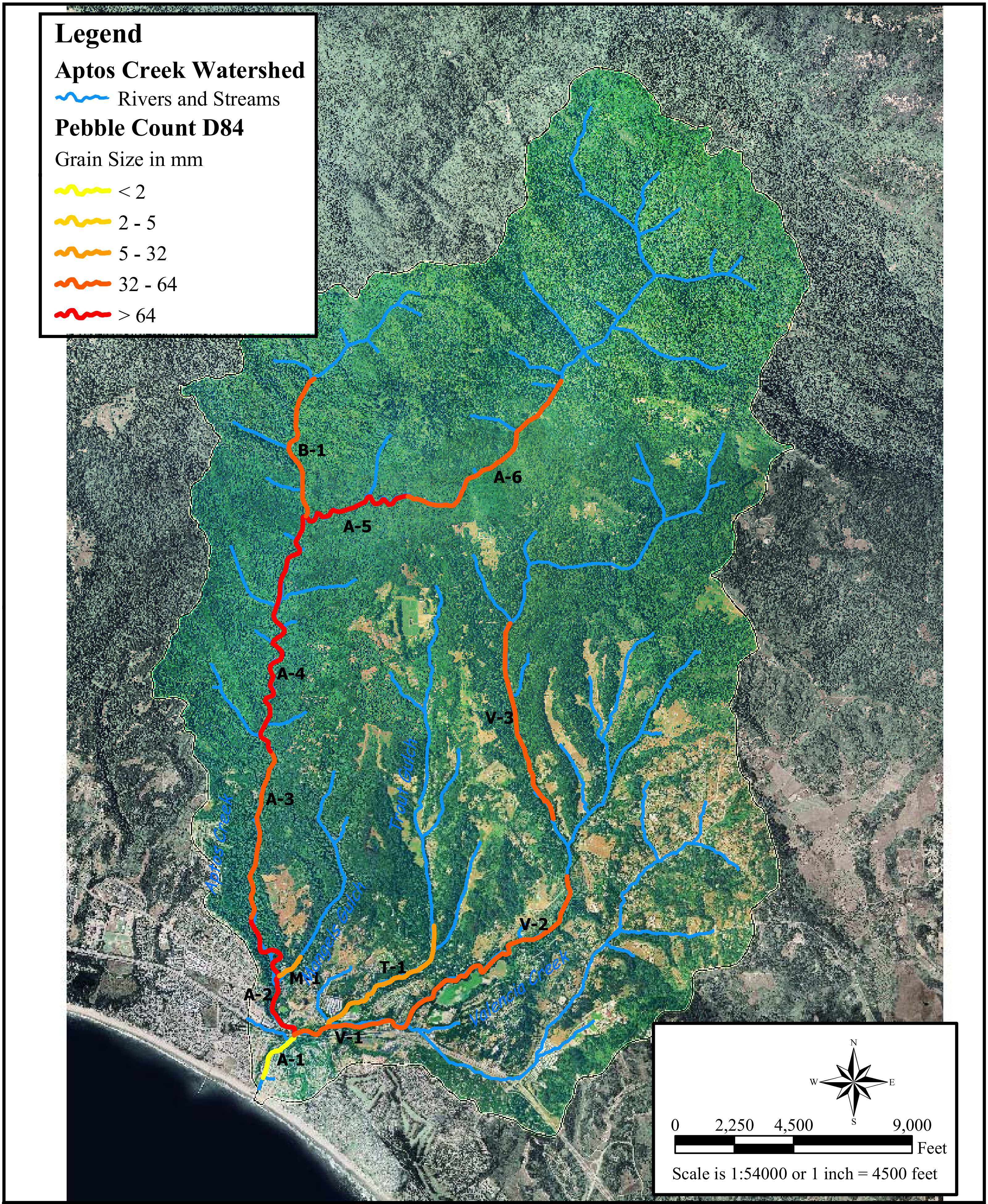
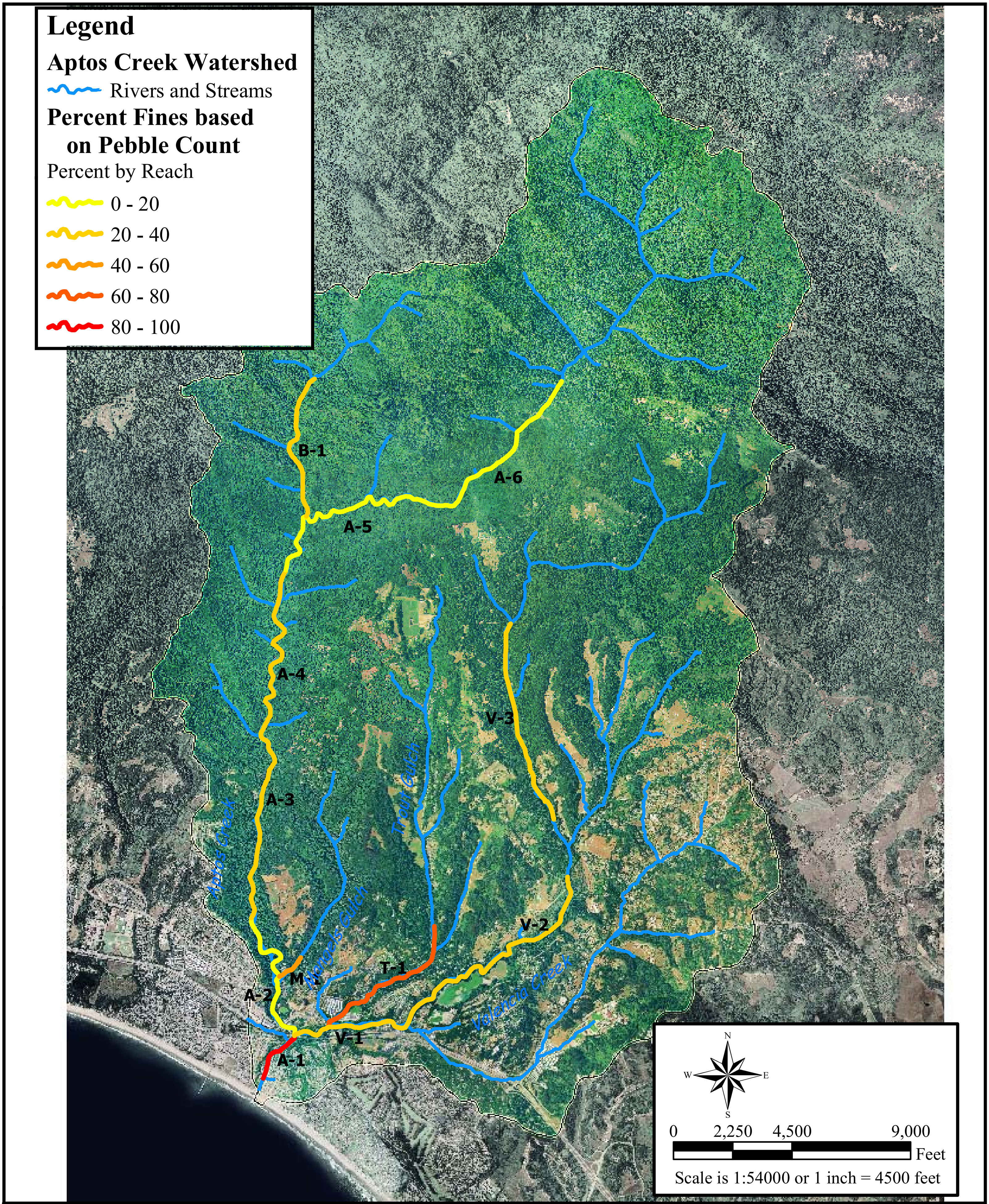


Swanson Hydrology and Geomorphology 115 Limekiln St. Santa Cruz, CA 95060 tel. 831-427-0288 fax. 427-0472	Pebble Count D84 at Pool Tails Aptos Creek Watershed Assessment and Enhancement Plan	Figure 15



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Percent Fines (<2mm) based on Pebble Count at Pool Tails
Aptos Creek Watershed
Assessment and Enhancement Plan

Figure 16

3.2.2 – Woody Material

The quantity of woody material within Aptos Creek is probably much lower than what it was historically but the density of wood appears to be comparable to the amount of wood found in tributaries to the San Lorenzo River such as Carbonera, Lower Zayante, Bear, and Boulder Creeks (Dvorsky, Alley, and Smith, 2002), except in selected reaches (Table 11; Figures 17-19). Woody material appears to be lacking in the lower reach of Aptos downstream of the Valencia confluence, which is probably due to local residences removing the wood out of fear of flooding or bank erosion.

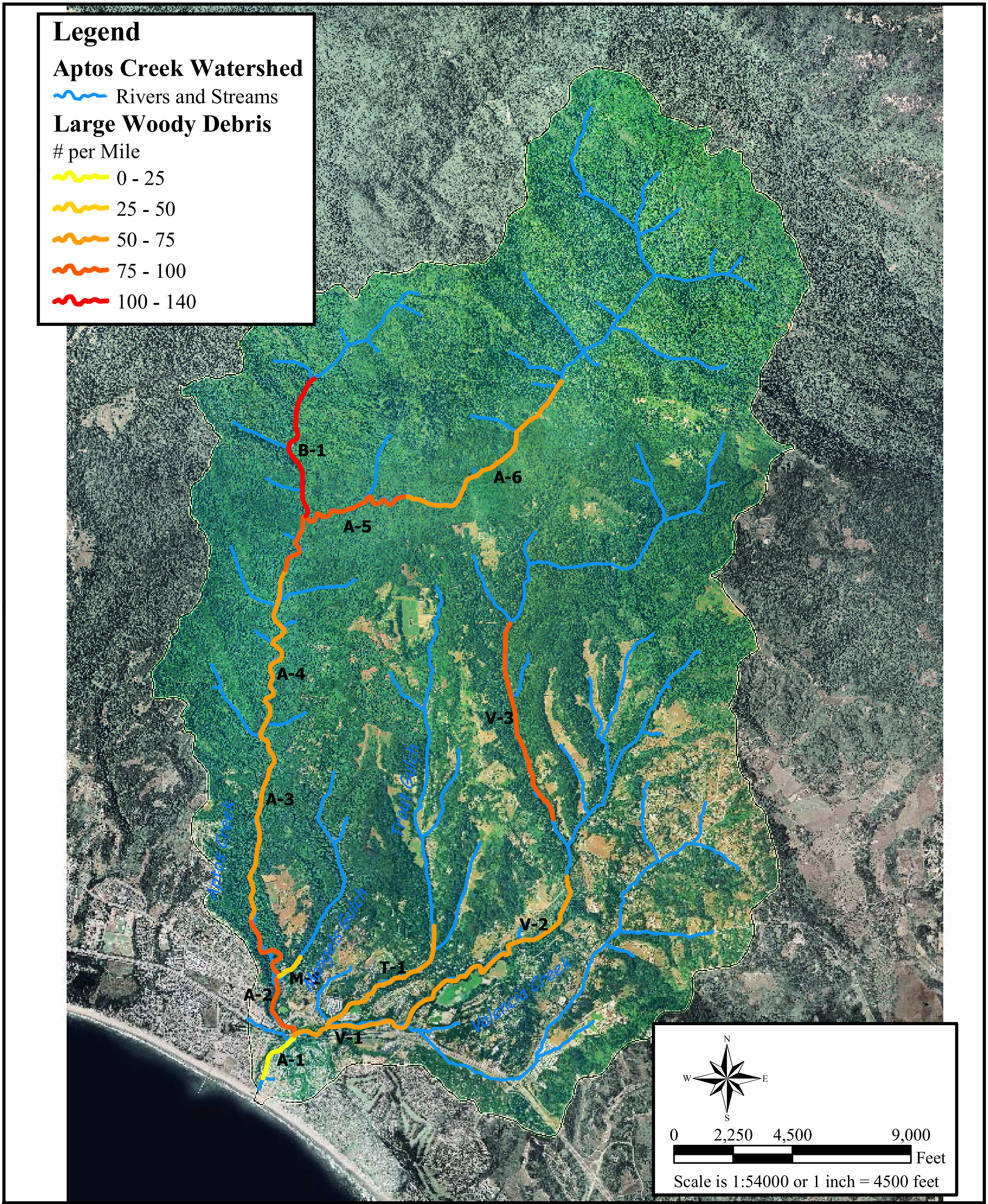
What appears to be lacking in the Aptos Creek Watershed are large rootwads, which provide stable roughness elements and aid in the formation of deep pools. Compared to surveyed tributaries to the San Lorenzo, many of the reaches within the Aptos Creek Watershed contain about 1/3rd to ½ of the density of root wads. It is not clear what mechanism would be acting in the San Lorenzo River Watershed to retain rootwads compared to conditions in Aptos, but if restoration efforts are aimed at introducing additional woody material, it may be appropriate to focus on adding stable rootwads to encourage pool scour.

The survey results also suggest a clear difference between Aptos and Valencia in terms of the role woody material plays in creating habitat for salmonids. According to the data, Valencia and Aptos have comparable densities of woody material. If woody material was performing the same habitat forming function in both watersheds, we would expect to see similar numbers of pools being formed as a result of the presence of woody material. The results presented in Figure 20 suggest otherwise. Several dozen pools were formed in both Aptos and Bridge Creek as a direct result of the presence of woody material. This is especially true in the reach of Aptos Creek that is located just upstream of the Valencia confluence (Reach 2). Conversely, in Valencia Creek, no pools were observed to have been formed due to the presence of woody material. We feel this is the direct result of the heavy sand load that is present in Valencia. Small pools may be forming during high flow winter months but are lost in summer as fine-grain sediment continues to be mobilized during the low flow months and settles out in the deeper, low velocity areas, ultimately filling the small pools.

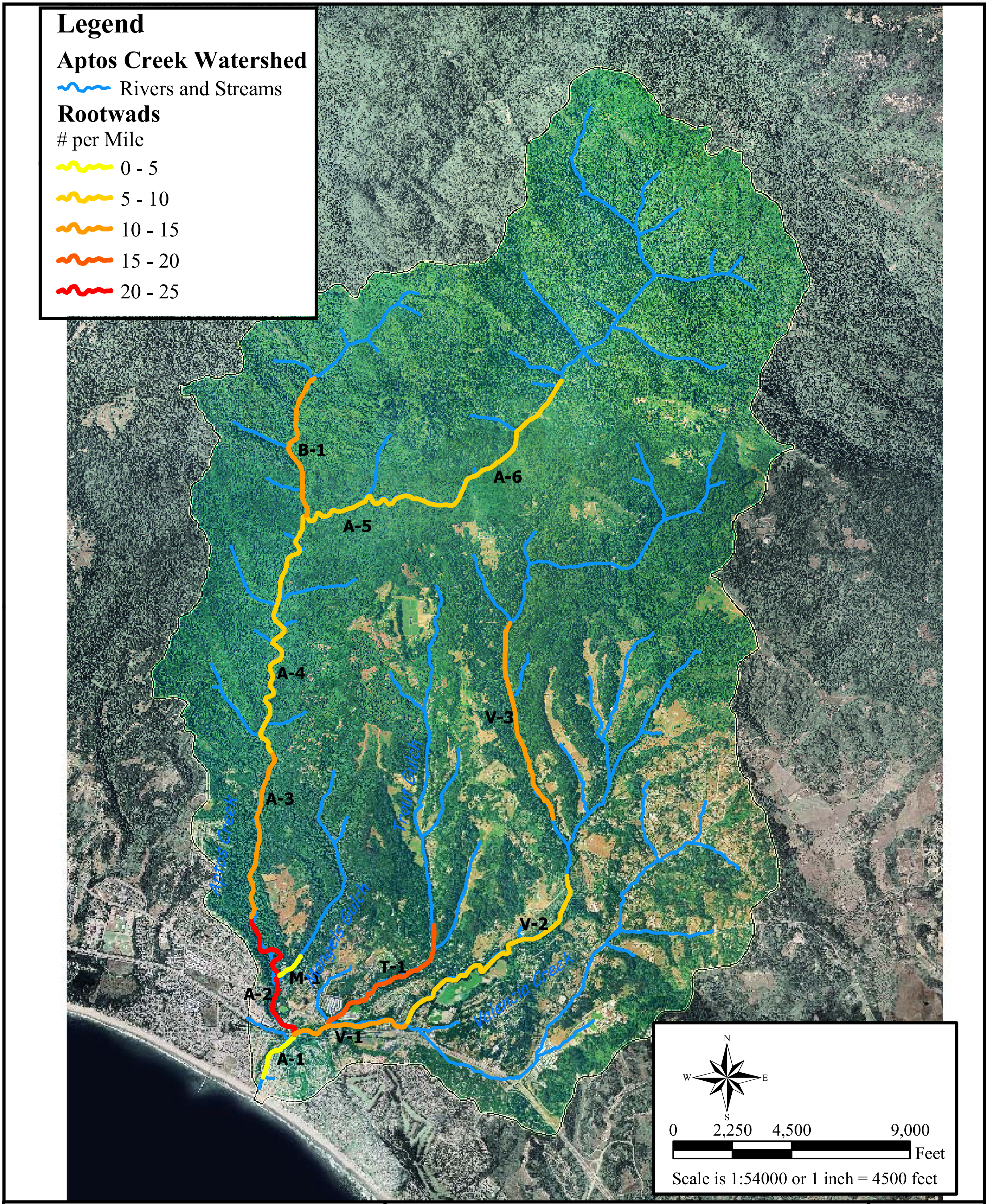
Reach-ID	Diameter 1-2'				Diameter 2-3'				All Size Classes		
	# logs per mile (6-20')	# logs per mile (> 20')	Total logs per mile	Rootwads (# per mile)	# logs per mile (6-20')	# logs per mile (> 20')	Total logs per mile	Rootwads (# per mile)	Total logs per mile	Rootwads (# per mile)	Log Jams (# per mile)
A-1	3.2	0.0	3.2	3.2	0.0	0.0	0.0	0.0	3.2	3.2	0.0
A-2	37.7	19.2	10.4	57.0	7.4	6.7	6.7	14.1	75.5	21.5	0.7
A-3	27.9	25.3	3.2	53.2	6.3	5.7	6.3	12.0	70.9	12.7	2.5
A-4	22.9	30.6	0.0	53.5	5.6	8.1	2.5	13.8	69.8	8.1	0.0
A-5	34.2	33.1	2.9	67.3	6.8	12.0	0.6	18.8	89.6	5.1	0.6
A-6	26.6	15.3	0.7	41.8	8.6	6.6	2.0	15.3	63.7	5.3	4.0
B-1	55.6	44.1	1.6	99.7	10.6	9.8	9.0	20.4	128.3	13.1	4.1
V-1	21.7	16.0	4.7	37.7	9.4	2.8	4.7	12.3	55.6	11.3	0.0
V-2	28.5	21.0	1.3	49.5	10.9	3.8	3.4	14.7	67.6	8.4	3.4
V-3	30.9	26.9	5.7	57.8	11.4	2.9	3.4	14.3	77.2	14.9	0.6
T-1	28.6	12.8	3.0	41.4	9.0	3.8	7.5	12.8	60.2	16.6	2.3
M-1	14.5	3.6	0.0	18.2	0.0	3.6	0.0	3.6	25.5	0.0	10.9

Reach-ID	Diameter 3-4'				Diameter > 4'			
	# logs per mile (6-20')	# logs per mile (> 20')	Total logs per mile	Rootwads (# per mile)	# logs per mile (6-20')	# logs per mile (> 20')	Total logs per mile	Rootwads (# per mile)
A-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A-2	2.2	0.7	3.7	3.0	0.7	0.7	0.7	1.5
A-3	2.5	1.9	2.5	4.4	0.6	0.6	0.6	1.3
A-4	1.5	0.5	3.6	2.0	0.5	0.0	2.0	0.5
A-5	0.6	2.3	1.1	2.9	0.0	0.6	0.6	0.6
A-6	4.0	1.3	1.3	5.3	1.3	0.0	1.3	1.3
B-1	4.9	2.5	2.5	7.4	0.0	0.8	0.0	0.8
V-1	3.8	0.9	0.9	4.7	0.9	0.0	0.9	0.9
V-2	0.8	1.7	2.1	2.5	0.0	0.8	1.7	0.8
V-3	2.3	1.1	5.1	3.4	1.7	0.0	0.6	1.7
T-1	3.8	0.8	3.0	4.5	1.5	0.0	3.0	1.5
M-1	3.6	0.0	0.0	3.6	0.0	0.0	0.0	0.0

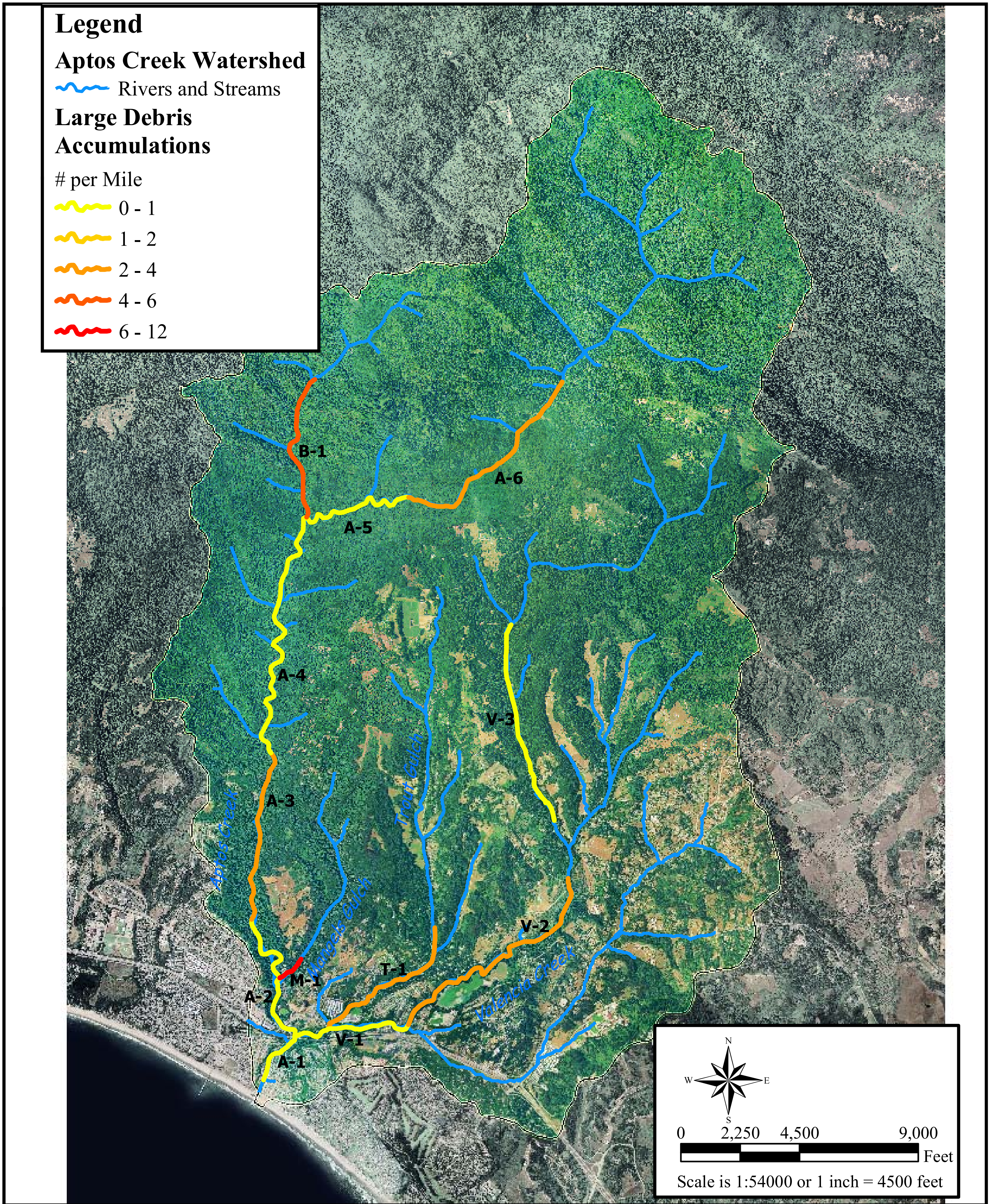
Table 11: Results from woody material survey for anadromous reaches identified in the Aptos Creek Watershed. The results are reported as # per mile. Results for reaches with a large number of log jams may be skewed since individual logs from the logjams were not included in the rest of the results.



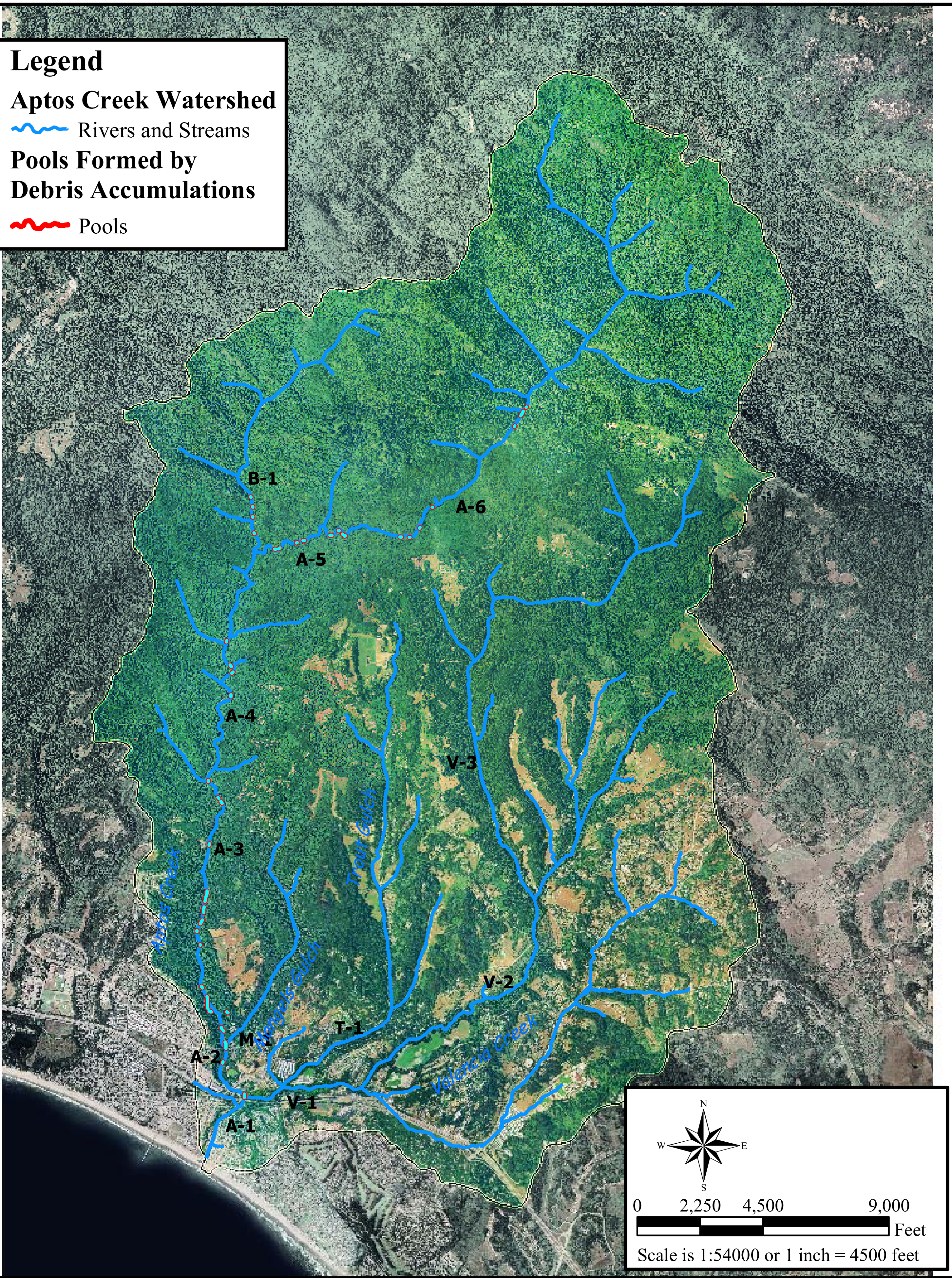
Swanson Hydrology and Geomorphology 115 Limekiln St. Santa Cruz, CA 95060 tel. 831-427-0288 fax. 427-0472	Number of Large Woody Debris Pieces per Mile of Stream Aptos Creek Watershed Assessment and Enhancement Plan	Figure 17



Swanson Hydrology and Geomorphology 115 Limekiln St. Santa Cruz, CA 95060 tel. 831-427-0288 fax. 427-0472	Number of Rootwads per Mile of Stream Aptos Creek Watershed Assessment and Enhancement Plan	Figure 18



Swanson Hydrology and Geomorphology 115 Limekiln St. Santa Cruz, CA 95060 tel. 831-427-0288 fax. 427-0472	Number of Large Debris Accumulations per Mile of Stream Aptos Creek Watershed Assessment and Enhancement Plan	Figure 19

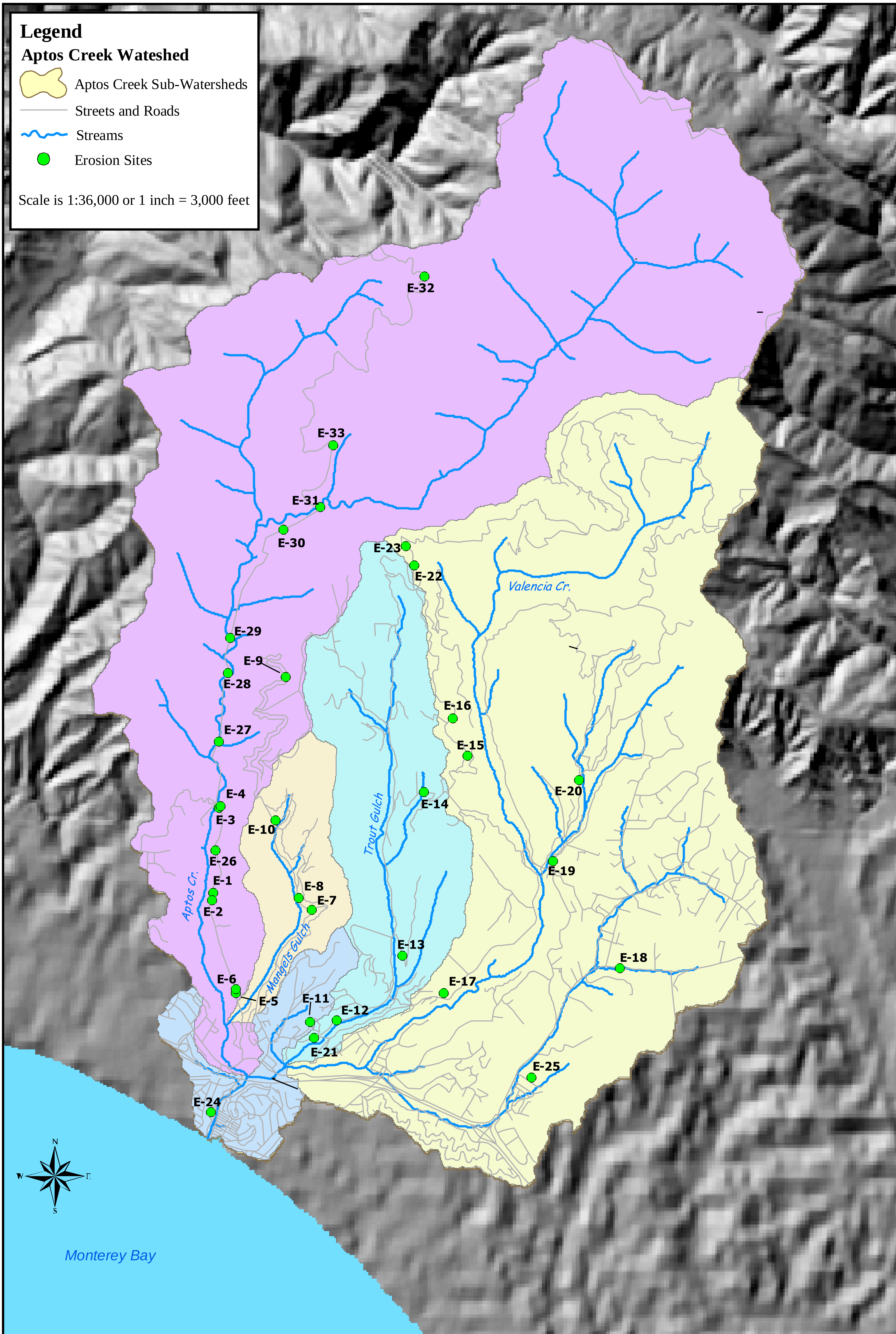


Swanson Hydrology and Geomorphology 115 Limekiln St. Santa Cruz, CA 95060 tel. 831-427-0288 fax. 427-0472	Pools Formed by Debris Accumulations Aptos Creek Watershed Assessment and Enhancement Plan	Figure 20

Examples of large woody debris jams found in the upper watersheds of Aptos and Bridge Creeks. In the photo on the left, the jam appears to be associated with a shallow landslide. On the photo on the right, a narrow bedrock section backs up both wood and sediment, creating a potential fish barrier.

3.3 – IDENTIFIED EROSION SOURCES

A total of 33 significant erosion sources were identified in the Aptos Creek Watershed during our reconnaissance survey of the road network (Figure 21; Table 11). Information collected at each site is meant to be preliminary and guide conceptual project development (Phase II of the Aptos Watershed Assessment). Sites will be prioritized in the future based on their severity, feasibility, and importance in terms of reducing direct input of fine sediment to stream channels. We consider the erosion source list to be a work in progress.



Swanson Hydrology and Geomorphology
115 Limekiln St. Santa Cruz, CA 95060
tel. 831-427-0288 fax. 427-0472

Aptos Creek Watershed
Erosion Features

Figure 21

Table 12: Significant erosion sources identified in the Aptos Creek Watershed from publicly accessible locations. Information collected at each site is meant to be preliminary.

Site #	Sub-Watershed	Location Description	Perceived Cause	Historical Context (previous fixes)	Height (ft)	Length (ft)	Erodibility (1-10)	Corrective Measure
E-1	Aptos Creek	2 miles up, on East side of Aptos Creek Rd., adjacent to incised trib.	Road cut on unstable slope	None	15	30	7	Vegetate
E-2	Aptos Creek	Just South of Site 1 on East side of road	Steep road cut on sandy slope	None	10	75	8	Vegetate
E-3	Aptos Creek	Trail on east side of Aptos Crk. Rd. at south end of steel bridge.	Foot traffic on steep slope; failed waterbar	Installed water-bar (failed)	NA	100	6	Add waterbar and repair existing bar
E-4	Aptos Creek	Trail cut immediately above site #3 on trail	High slope on cut for access trail	None	15	50	7	Improve trail drainage at toe
E-5	Aptos Creek	.5 miles up Aptos Crk. Rd. (west side) at retaining wall.	Perched culvert (15'); low vegetation; steep slope	Rock in channel below culvert	10.5	25	7	Flume extension and/or larger rock
E-6	Aptos Creek	Just North of site 5, on the west side of Aptos Creek Rd. (.5 mile)	Perched culvert (3')	None	4	100	7	Flume extension and/or rock in channel
E-7	Mangels Gulch	800 Redwood Drive on west side.	Geographic low pt/convergence of road drainage	Mulched with limbs and veg debris	20	NA	6	Vegetate
E-8	Mangels Gulch	837 Redwood Drive (west side)	Slumping road shoulder; adjacent perched culvert	Black plastic secured with rock	6	17.5	7	Vegetate
E-9	Aptos Creek	Upper Redwood Dr. incised trib adjacent to large green water tank	Geographic low pt with low bank stability	Debris traps, some rock in channel	3	NA	7	larger and more rock in channel
E-10	Mangels Gulch	Intersection of Campus Rd. and Redwood Dr.	Unstable bank from road cut	None	10	60	6	NA
E-11	Trout Gulch	890 Old Farm Lane off Trout Gulch Rd.	Geographic low point; tributary to trout gulch	Retaining wall and 6" drain rock (at lower end)	2.5	NA	6	Stabilize banks and bed with veg and rock
E-12	Trout Gulch	996 Trout Gulch Rd.	Road cut on unstable slope	None	20	45	7	Vegetate

Table 12: Significant erosion sources identified in the Aptos Creek watershed from publicly accessible locations. Information collected at each site is meant to be preliminary.

Site #	Sub-Watershed	Location Description	Perceived Cause	Historical Context (previous fixes)	Height (ft)	Length (ft)	Erodibility (1-10)	Corrective Measure
E-13	Trout Gulch	Approx. .25 miles up Los Arboles Rd off Trout Gulch Rd.	Road cut on steep, unstable slope	Tire retaining wall adjacent to site; debris trap	15	55	8	Vegetate; retaining wall
E-14	Trout Gulch	Valencia School House Rd.; .5 miles from Trout Gulch Rd.	Road -side ditch converging with incised trib.	None	10	NA	8	Vegetate bank; rock in channel
E-15	Trout Gulch	Just before 1455 Fern Flat Rd. off Val. School House ("children at play" sign)	Road cut and fill deposit	Failed vegetation effort	100	40	10	Vegetate and apply netting
E-16	Valencia Creek	Beyond 2360 Fern Flat Rd.; 1.5 mi. south of inter. of Fern Flat and T. Gulch	Road cut on unstable slope	graded at toe; cc debris wall on lower shoulder	15	40	8	Vegetate
E-17	Valencia Creek	980 Valencia Rd; .94 Mi.; just north of Cherokee Ln.	Road cut on unstable slope	Failed netting	20	100	9	Vegetate
E-18	Valencia Creek	6070 Freedom Blvd. To Lore Way (east side)	Roadside ditch convergent with geologic low point.	None	12	NA	7	Rock in Channel
E-19	Valencia Creek	260 Cox Rd. off Valencia Rd.	Road cut on steep, unstable slope	Black plastic secured with rock on shoulder	50	50	10	Vegetate and apply netting
E-20	Valencia Creek	Across from 801 Bear Valley Rd (Bean Hill on Map?) off Valencia Rd.	New road cut across channel from top of bank	New Development	40	100	10	Block access, vegetate, add waterbars
E-21	Trout Gulch	Just south of Trout Gulch/Valencia Intersection, adjacent to retaining wall	Road cut too steep	None	15	100	8	Retaining wall
E-22	Valencia Creek	Fern Flat Rd. just beyond Intersection with Trout Gulch	Failed road cut	None	10	100	6	NA
E-23	Valencia Creek	Fern Flat Rd., .5 mi. from Trout Gulch Rd.; 100 yrds from #22	Road cut on unstable slope	None	50	60	8	Vegetate and apply netting
E-24	Aptos Creek	120 Glen Dr. (Spreckles > Creek Dr > Glen)	Landslide (steep slope)	1 foot retaining wall at toe.	20	15	8	Vegetate

Table 12: Significant erosion sources identified in the Aptos Creek watershed from publicly accessible locations. Information collected at each site is meant to be preliminary.

Site #	Sub-Watershed	Location Description	Perceived Cause	Historical Context (previous fixes)	Height (ft)	Length (ft)	Erodibility (1-10)	Corrective Measure
E-25	Valencia Creek	Hillside off north side of Mariner Way (driveway for Aptos High School)	Devegetation on sandy slope/ vehicle traffic	None	30	NA	10	Vegetate and block access
E-26	Aptos Creek	Aptos Creek Rd; approx. .25 miles north of site 1; adjacent to "area closed" sign.	Old logging road cut	Access closed	NA	50	9	Vegetate
E-27	Aptos Creek	.25 mi. N. of W. Trail/Aptos Crk. Rd. inter.; just S. of Mary Easton picnic area	Road cut	None	12	NA	9	Vegetate on toe (upper slope too steep)
E-28	Aptos Creek	Just N. of Mary Easton picnic area on West side of Aptos Creek Rd.	Two successive landslides from road cut	None	40	NA	10	Vegetate
E-29	Aptos Creek	Sout end of Margaret's Bridge.	Old road route across creek bed	Construction of bridge	NA	45	9	Vegetate
E-30	Aptos Creek	.2 mi. N. of Aptos Creek Fire Rd. gate on E. road side.	Road cut	None	30	NA	8	Vegetate
E-31	Aptos Creek	Where Aptos Cr. Rd. crosses bed of Aptos Creek.	Vehicle traffic on stream bed	Construction of footbridge	NA	30	8	Construction of bridge
E-32	Bridge Creek	Approx. .2 mi. S. of sand point on E. side of fire road.	Road cut	None	40	NA	10	Vegetate
E-33	Aptos Creek	.5 mi. N. of creek bed crossing on W. side of road.	Road cut	None	45	NA	8	Vegetate

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APPENDIX A: LARGE WOODY DEBRIS INVENTORY DATA SHEET

L W D   I N V E N T O R Y   F O R M

Stream: ______________________ **Sample** _____ **of** _____ **Reach No.** ______

Date ___/___/___ **Drainage:** ____________________ **USGS Quad:** ______________

Reference Point: ____________________________ **Sample Length (Ft)** __________

Reach Location (Feet From Ref.Pt) Start ________ Stop ________ Total ________

Lat __ __ __ N **Long** ___ __ __ W (Reach start or Ref.Pt.) **T** ____ **R** ____ **S** ____

Surveyors: ____

CHANNEL CHARACTERISTICS (Attach Channel Typing Form)

Discharge Q ________cfs Gradient ________ % Channel Type:__________

Percent Substrate in Boulders: (1'- 3') _______%; (>3') _______%

Air Temp _______ Water Temp _______

	Right Bank % Slope ________ Dom. Veg.________					**Stream** Dom. Veg.________				**Left Bank** % Slope ________ Dom. Veg.________				
	D/D	D/S	Per	Live C	Live D	Dead/ Down	D/S	Live C	Live D	D/D	D/S	Per	Live C	Live D
1-2d 6-20														
Root														
1-2d >20'														
2-3d 6-20														
Root														
2-3d >20'														
3-4d 6-20														
Root														
3-4d >20'														
>4d 6-20														
Root														
>4d >20'														

Note any LDAs (log jams), estimate size LxWxH and no. pieces. Note if gravel is retained upstream. Tally live conifer "C" and deciduous "D" trees separately. Tally root wads by diameter of "trunk". Include root wads <6' total length.

Comments:

APPENDIX B: PEBBLE COUNT SURVEY RESULTS

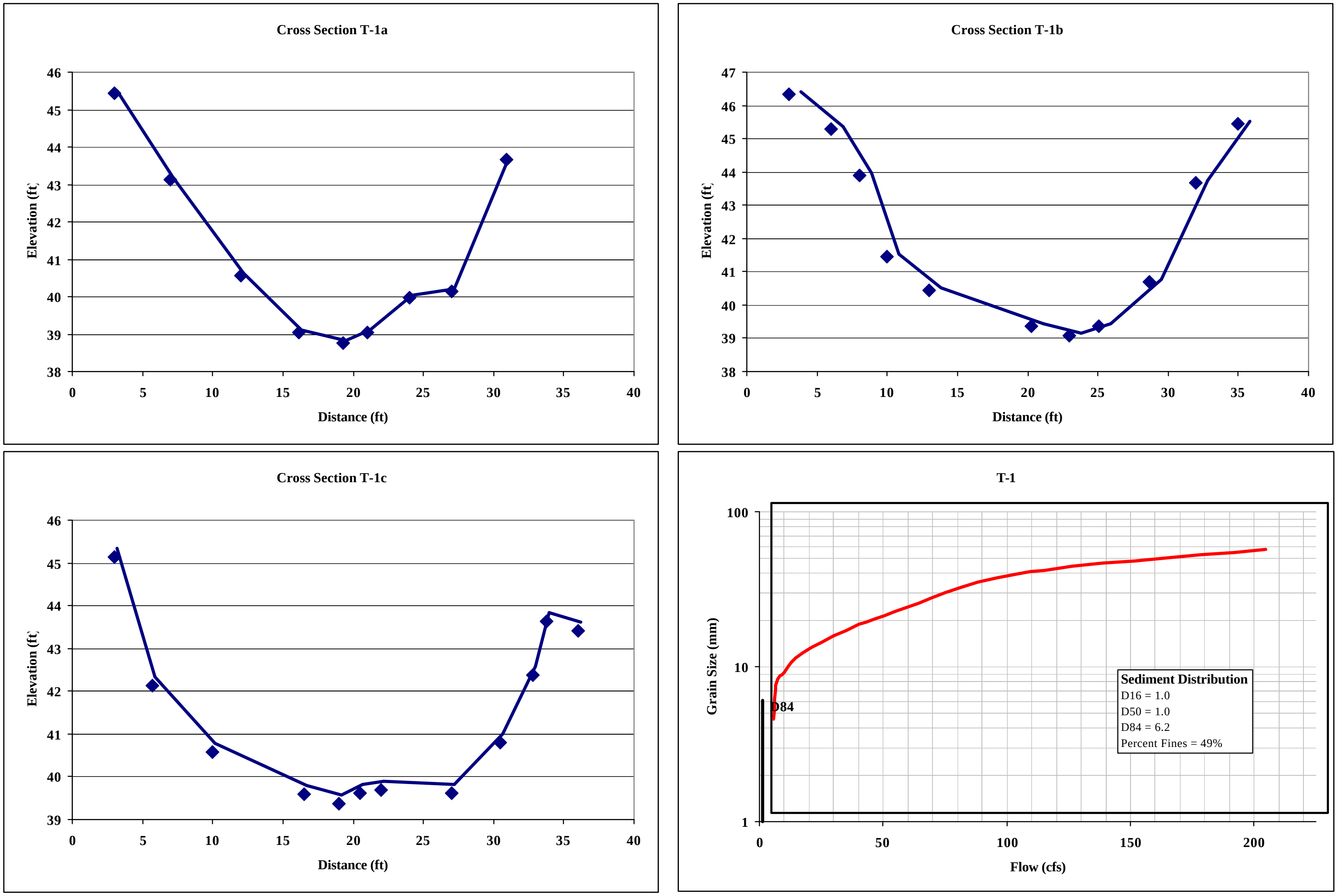


Figure B-1: Survey Site #1 in Trout Gulch. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

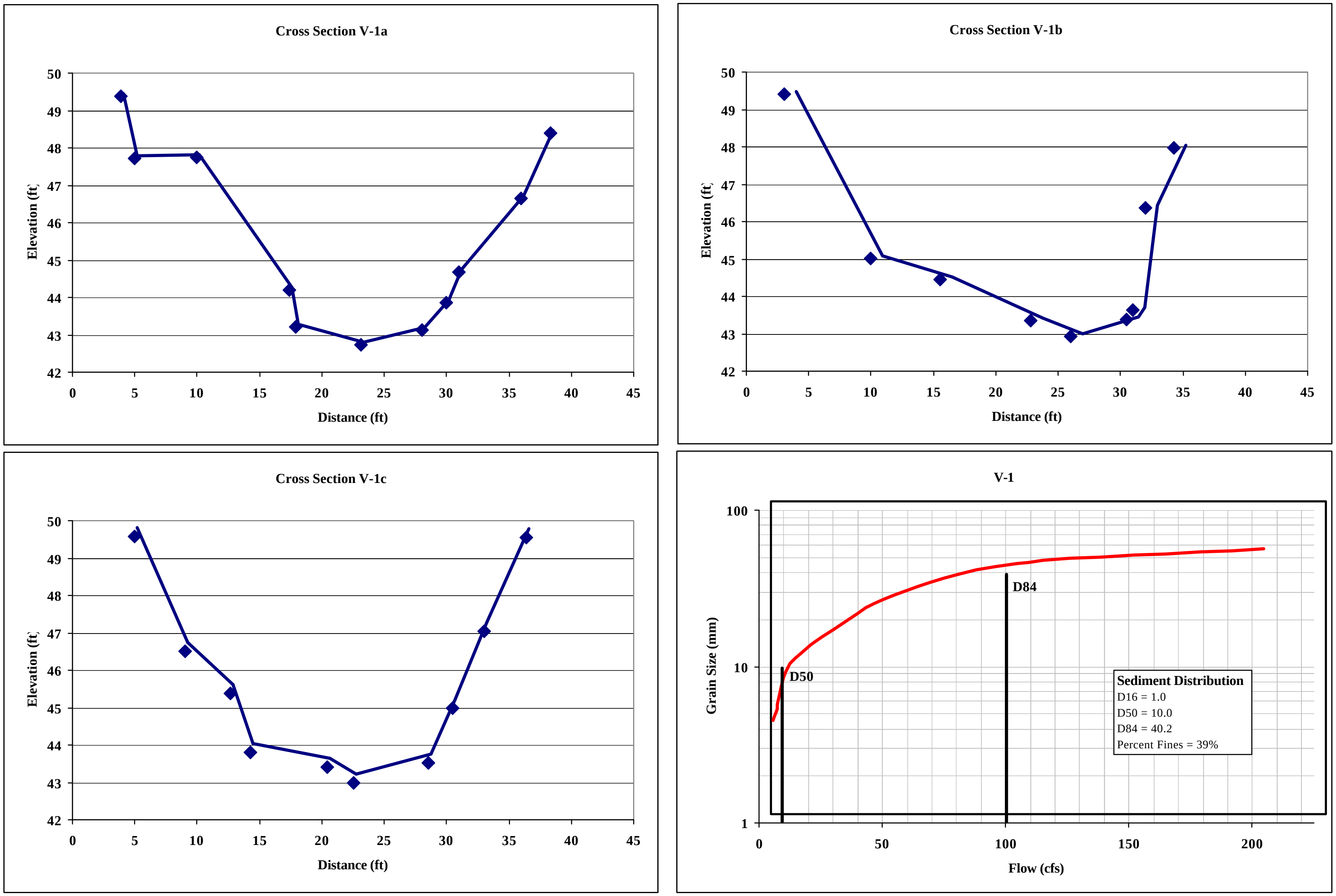


Figure B-2: Survey Site #1 in Valencia Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

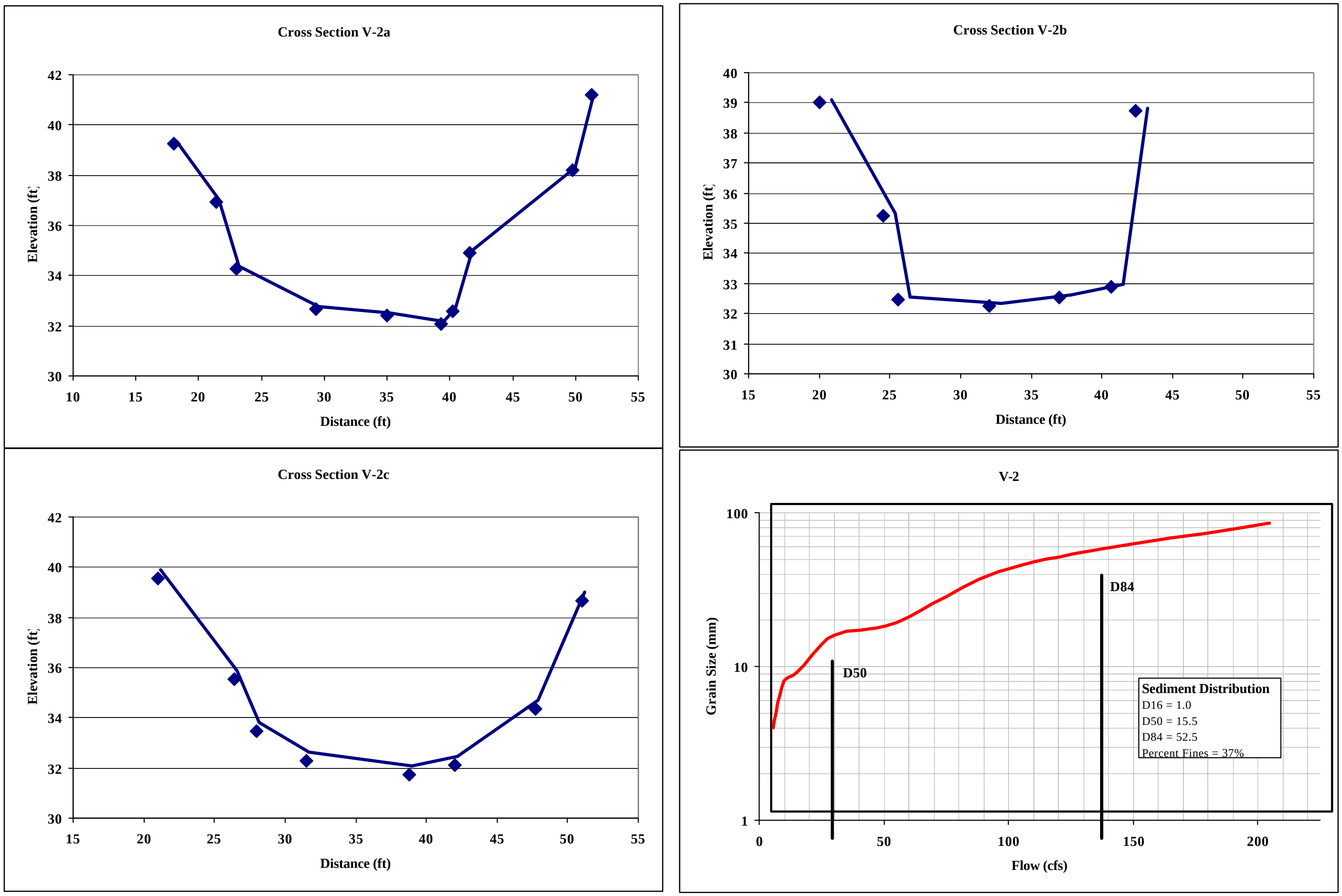


Figure B-3: Survey Site #2 in Valencia Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

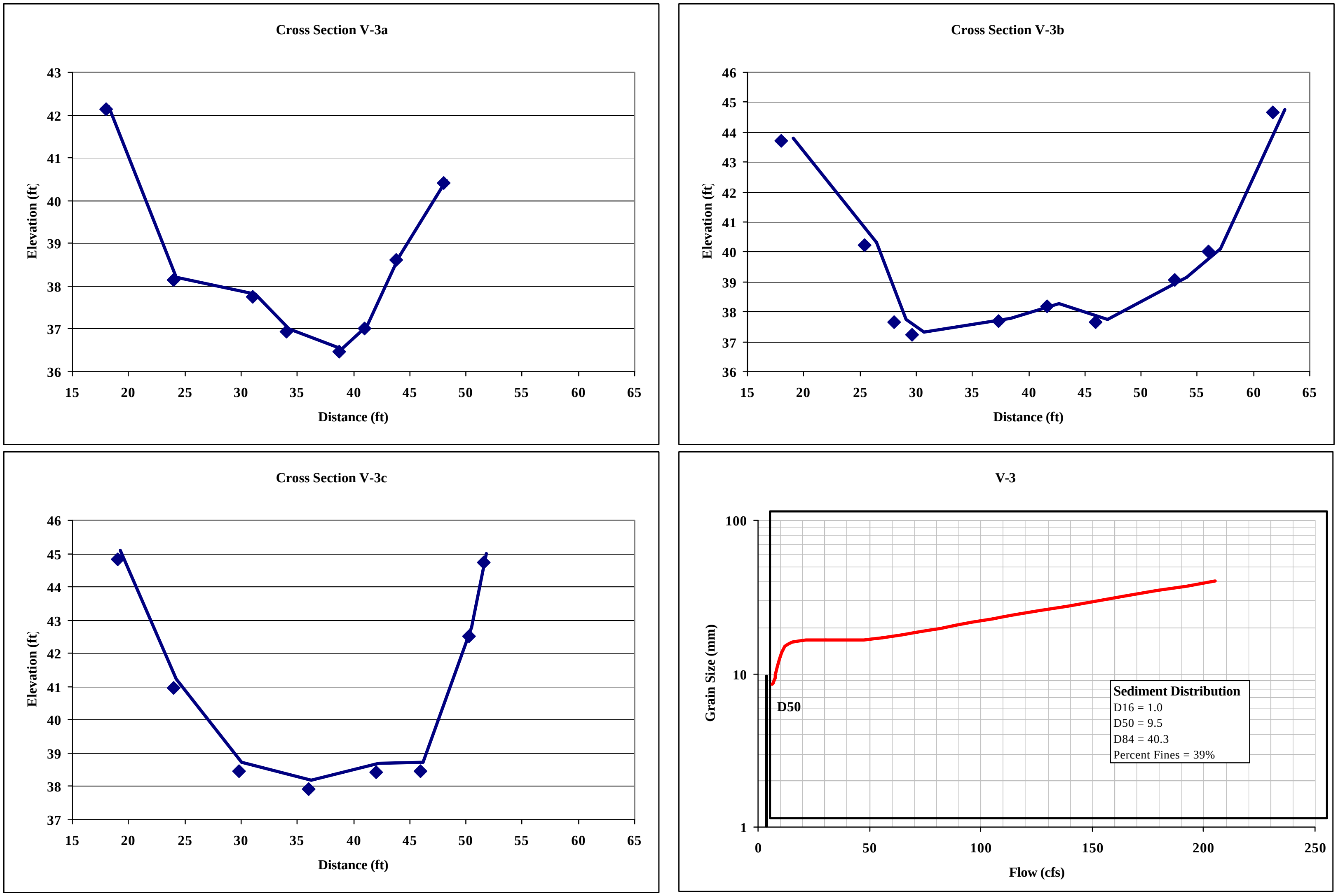
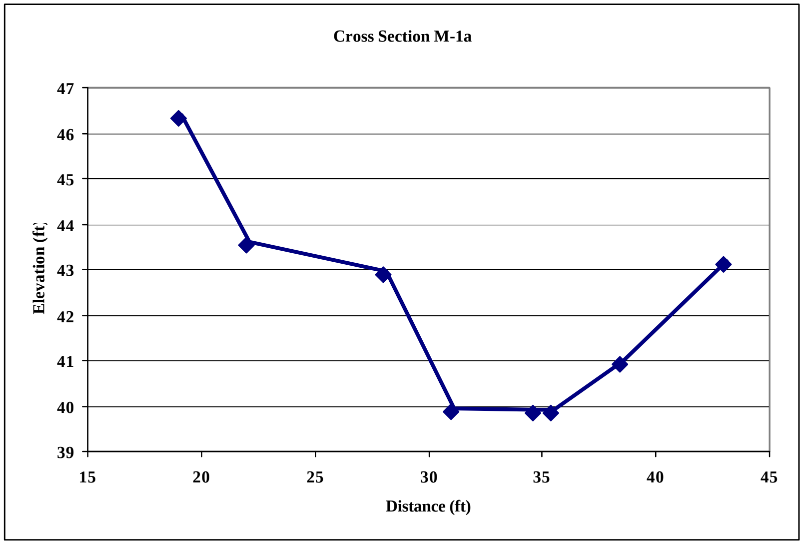
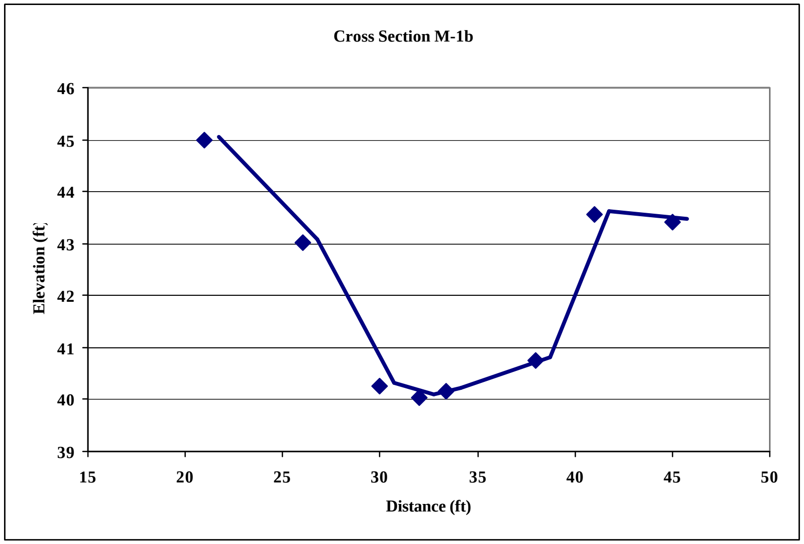
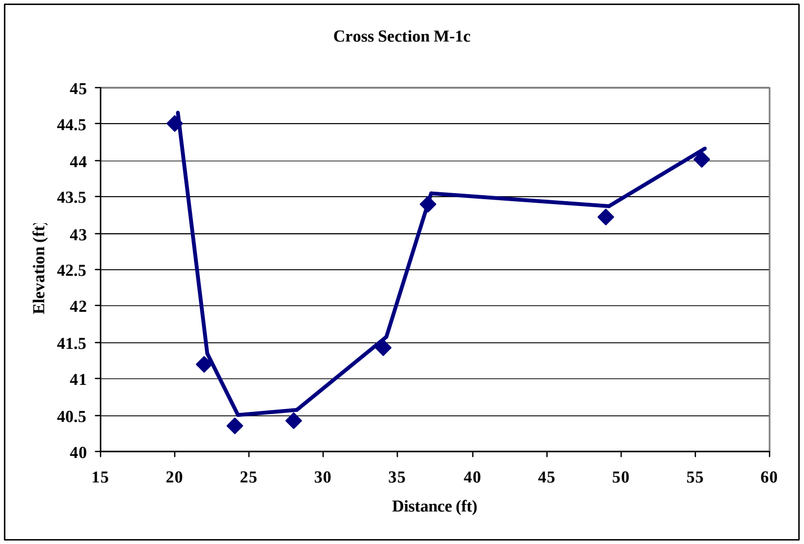


Figure B-4: Survey Site #3 in Valencia Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.







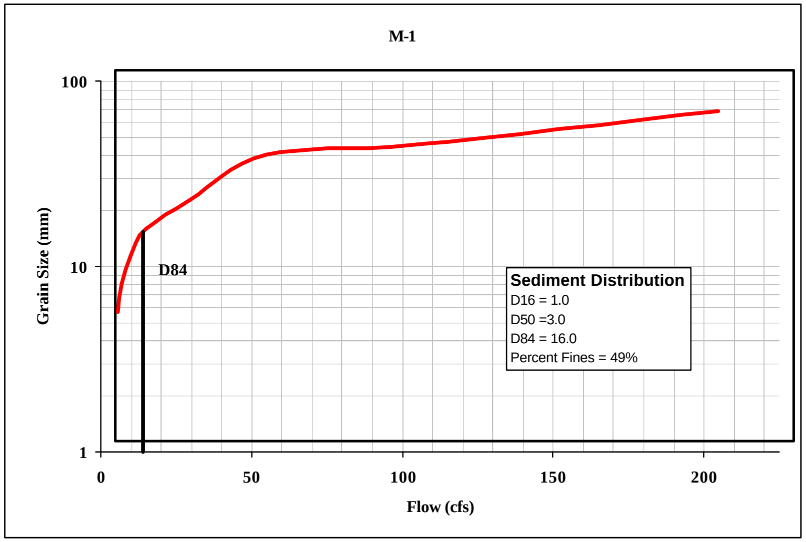


Figure B-5: Survey Site #1 in Mangels Gulch. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

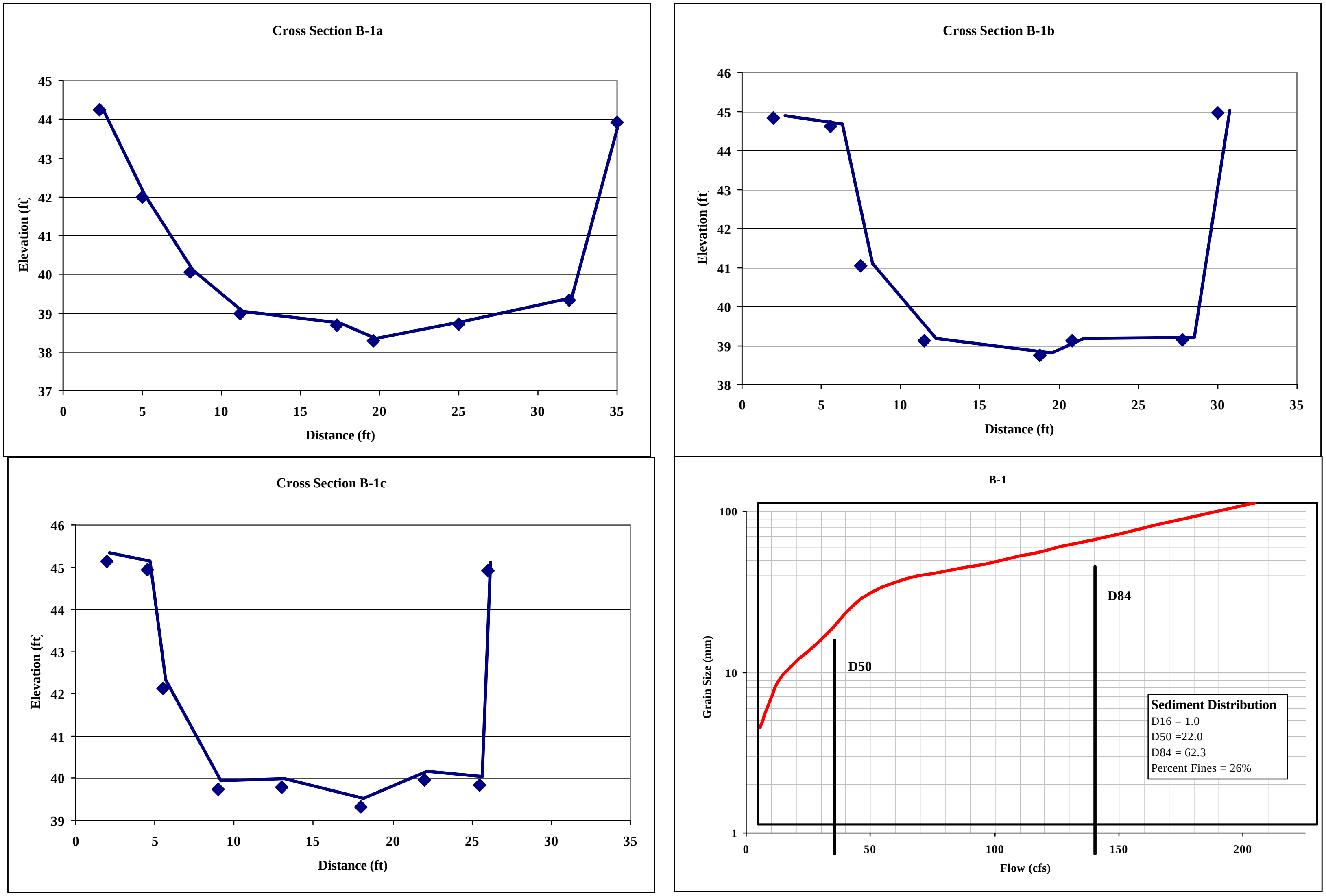
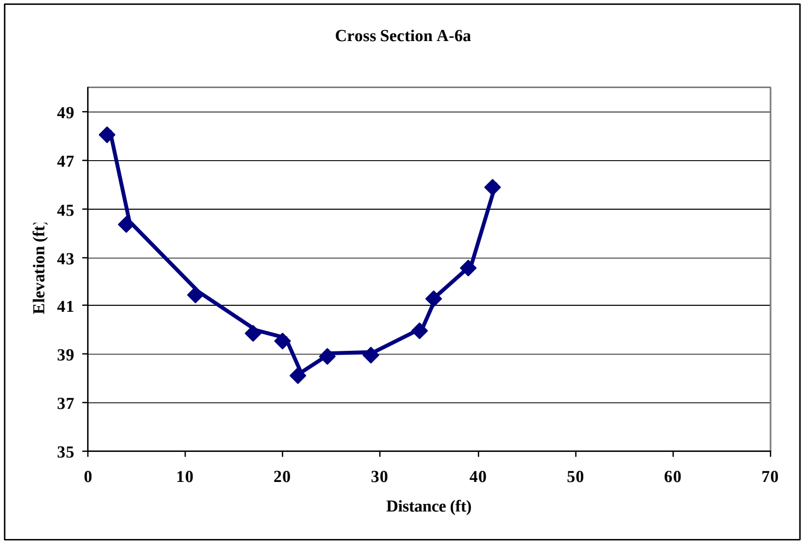
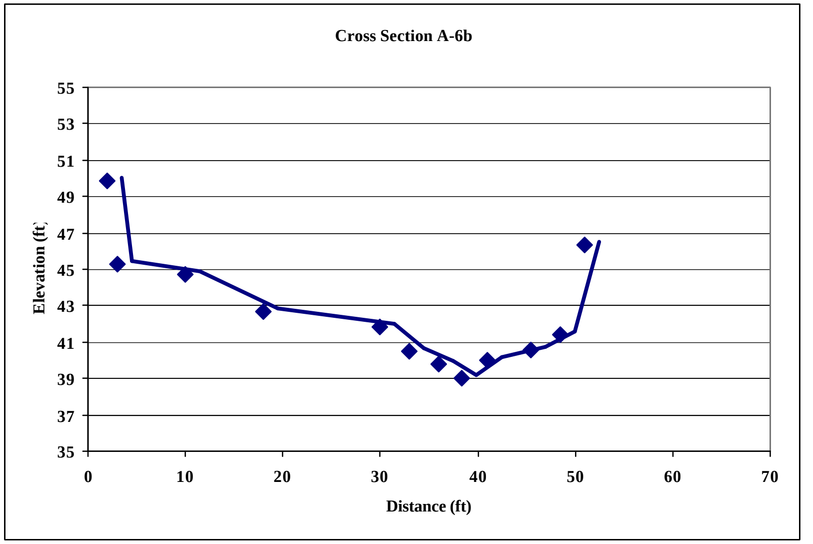
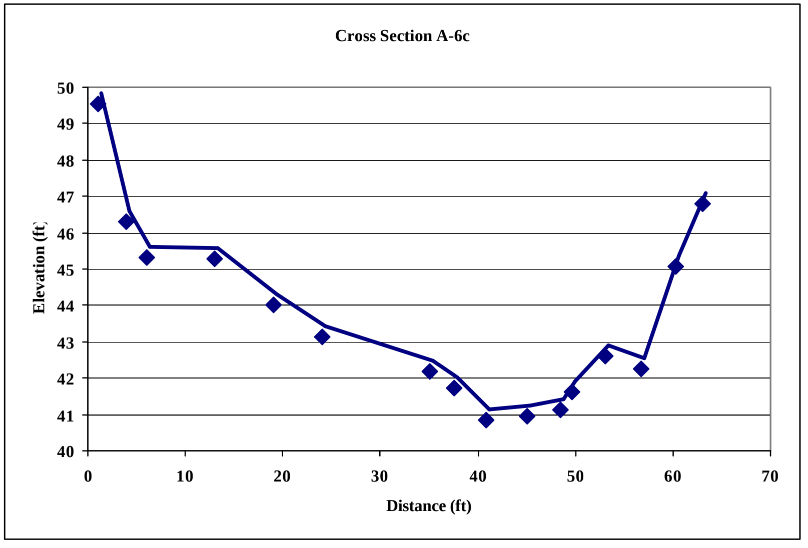


Figure B-6: Survey Site #1 in Bridge Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.







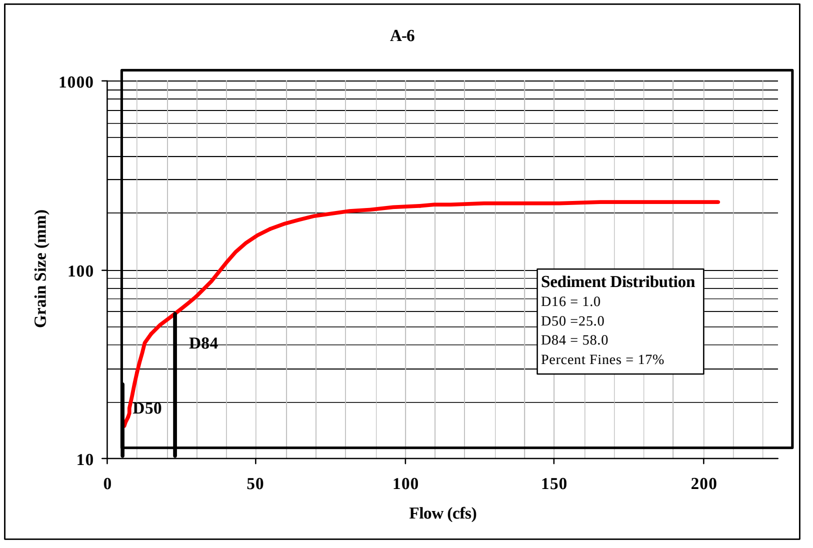


Figure B-7: Survey Site #6 in Aptos Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

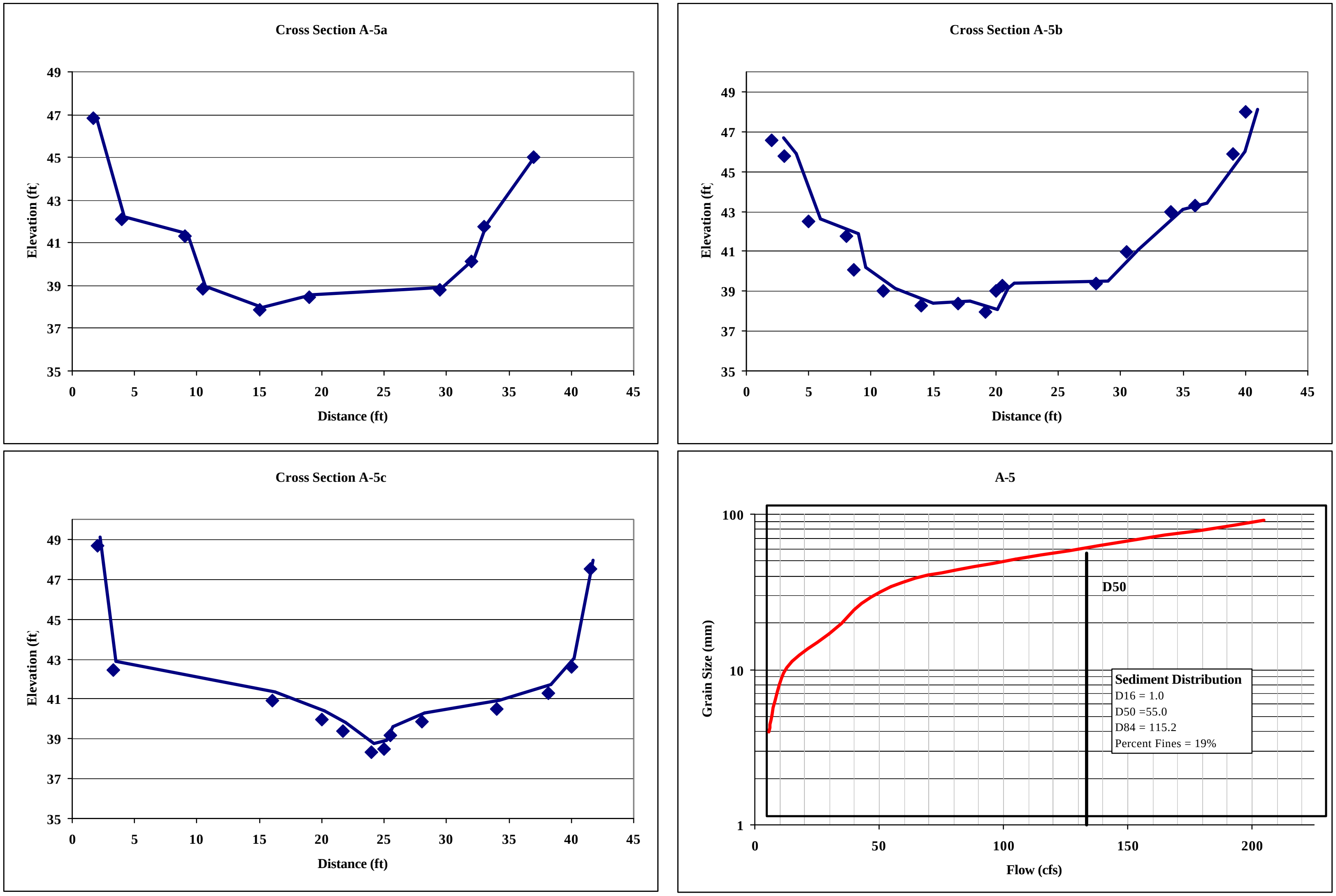
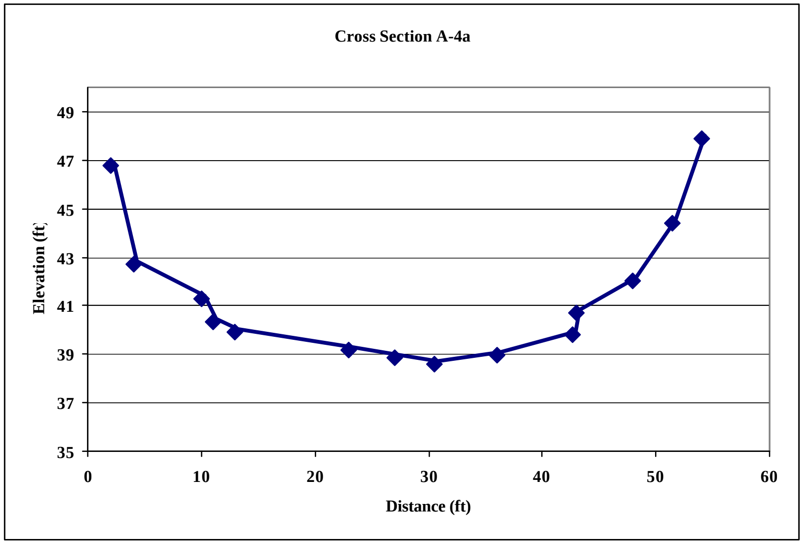
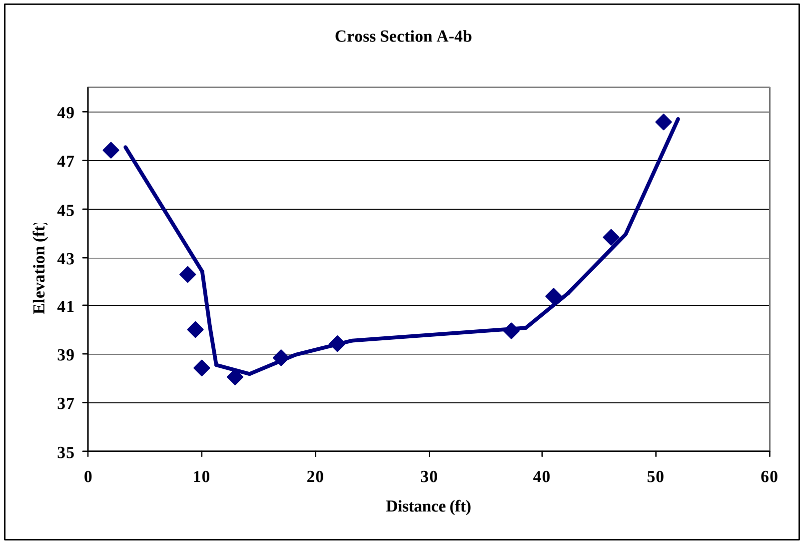
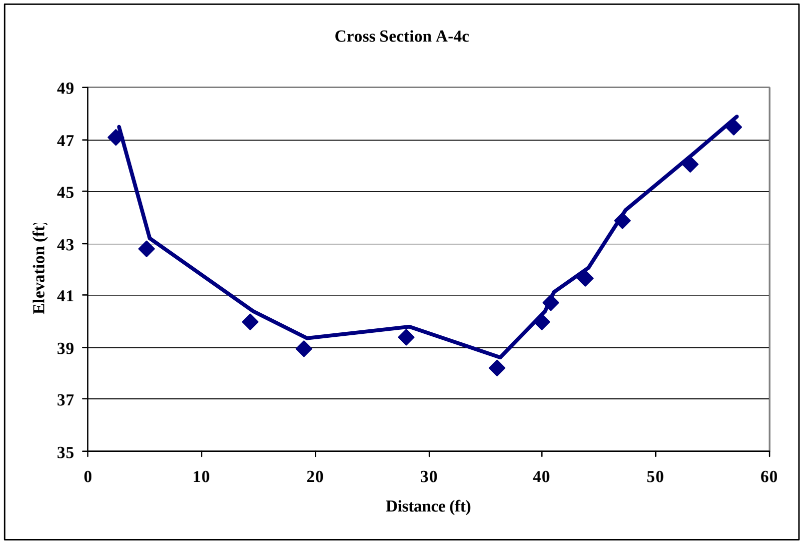


Figure B-8: Survey Site #5 inAptos Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.







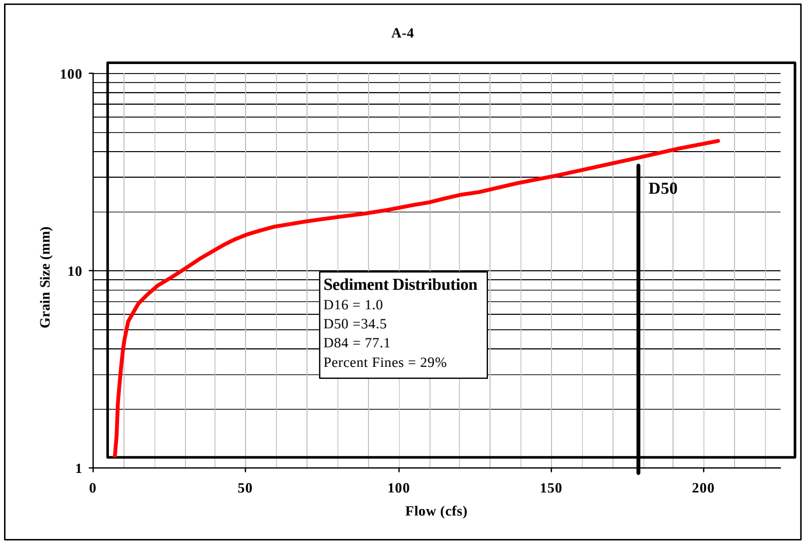
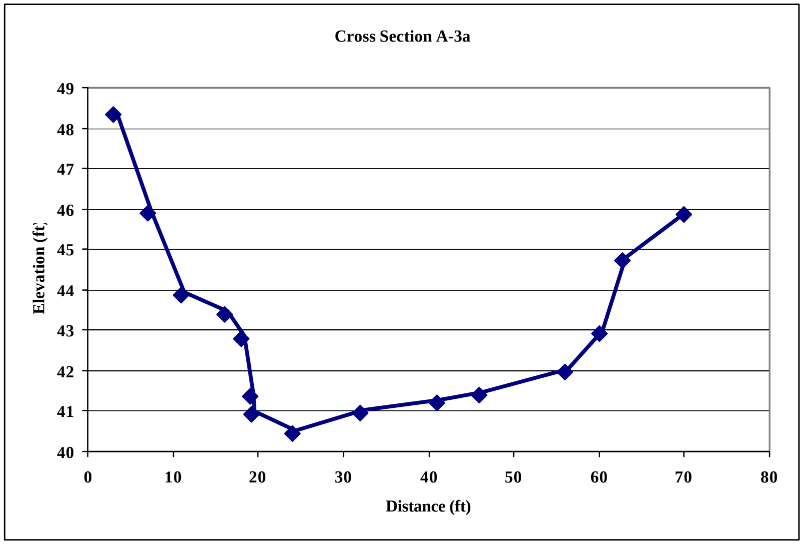
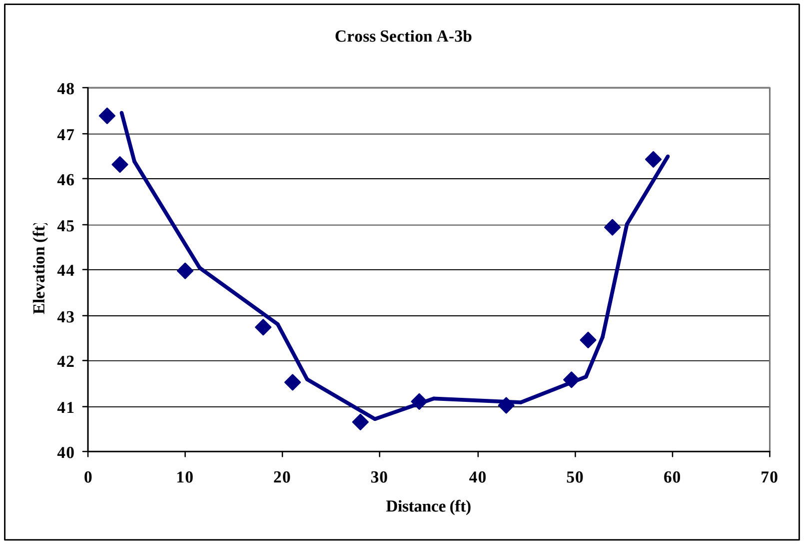
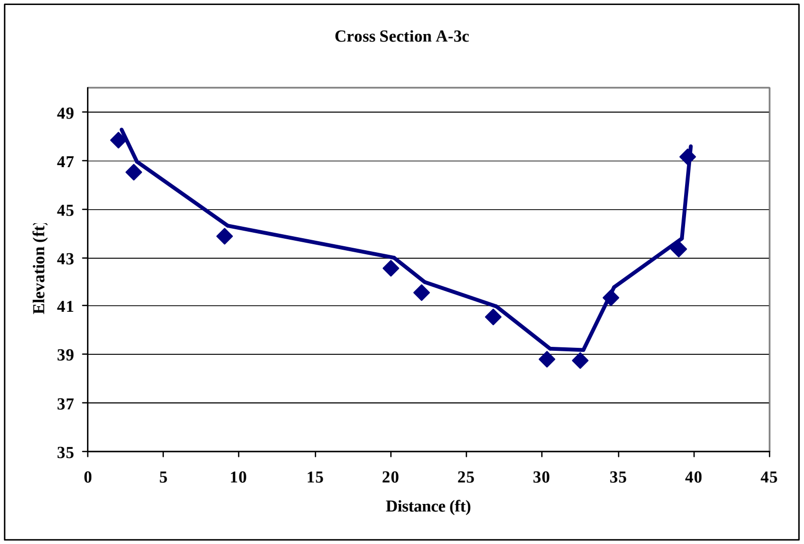


Figure B-9: Survey Site #4 in Aptos Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.







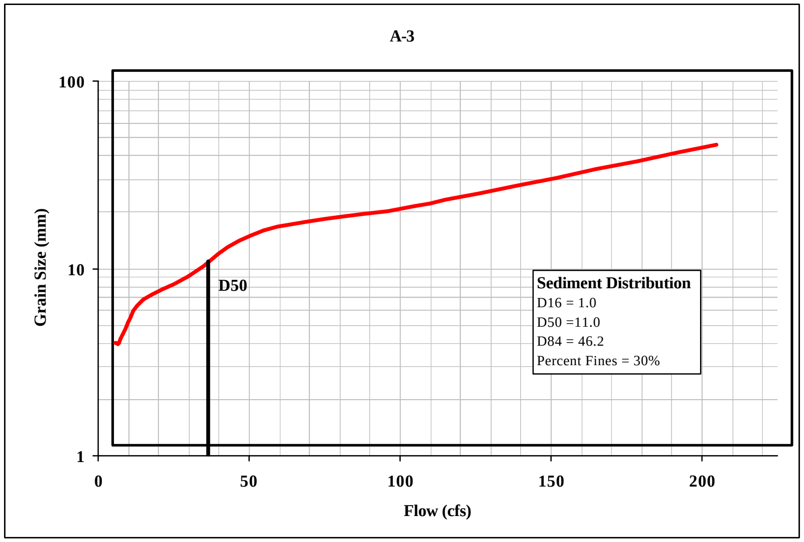


Figure B-10: Survey Site #3 in Aptos Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

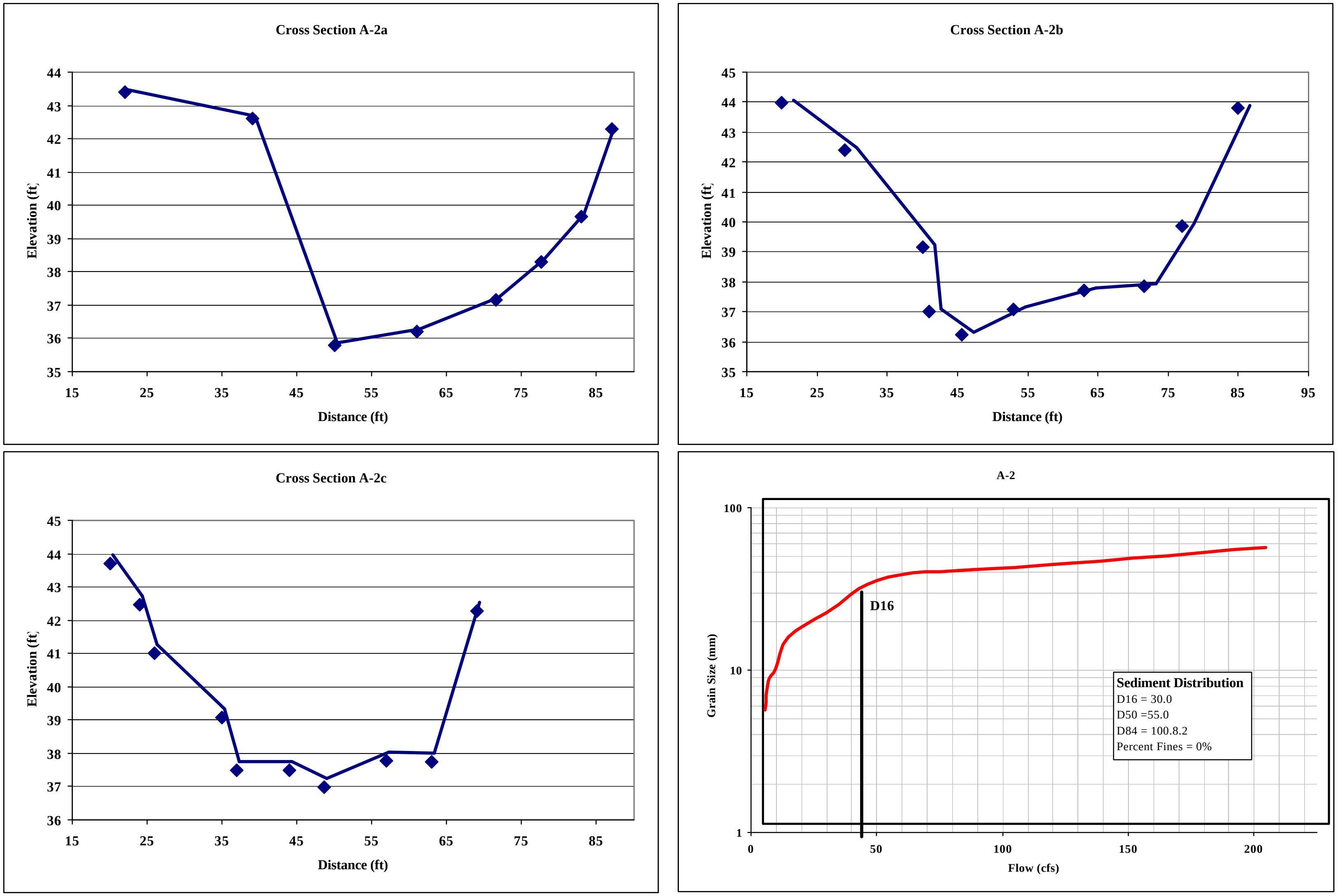


Figure B-11: Survey Site #2 in Aptos Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

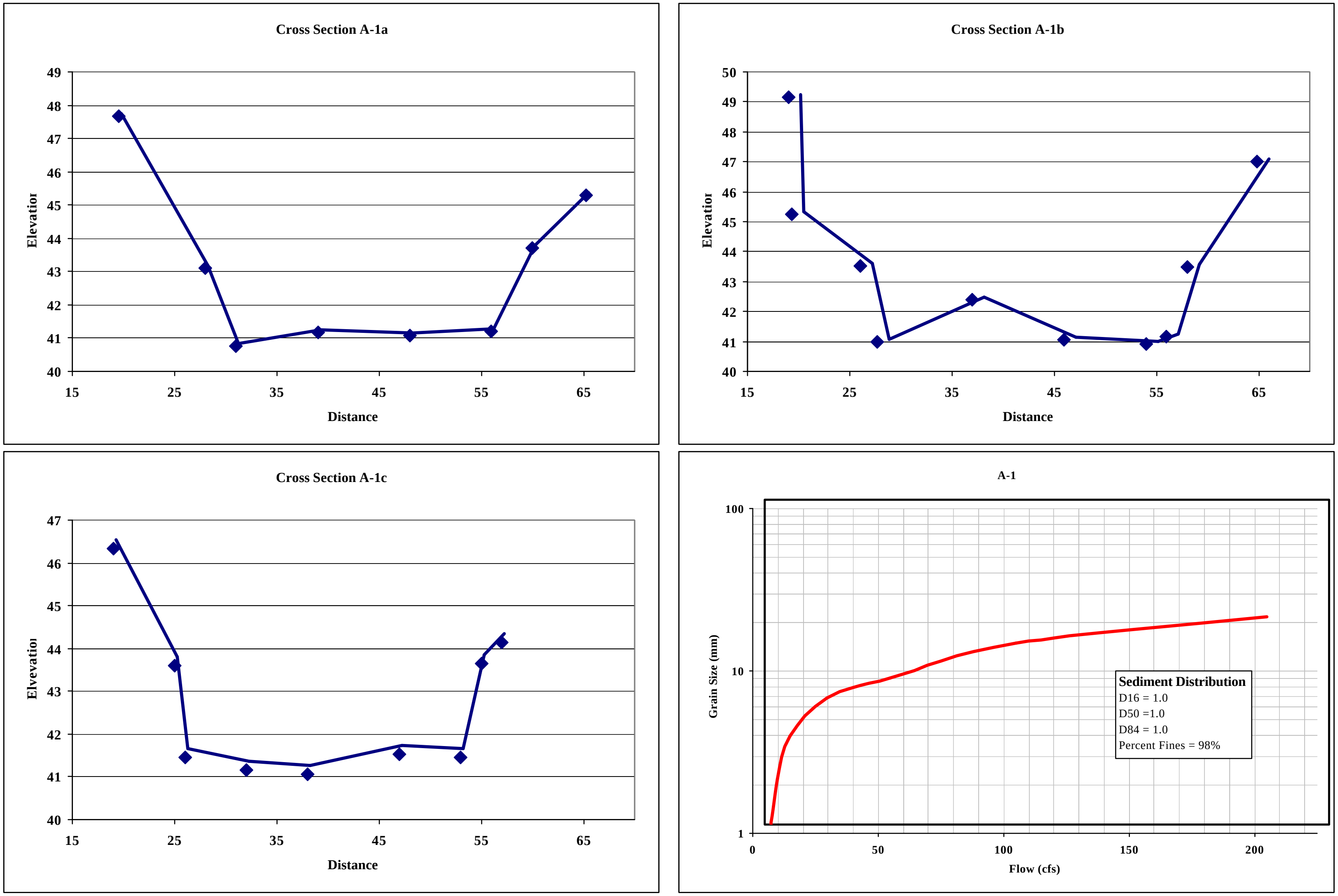


Figure B-12: Survey Site #1 in Aptos Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.